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A COMPARATIVE STUDY OF TECHNIQUES FOR FORECASTING MONTHLY AIRCRAFT SORTIE RATES IN THE TACTICAL AIR COMMAND

THESIS

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Everett R. Pincolini

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Abstract

This research compared the results of four time series forecasting techniques to the forecasting methodology currently used at wings in the Tactical Air Command (TAC) for determining the monthly aircraft sortie schedule. The number of aircraft scheduled has an effect on the work force throughout the maintenance complex. A more accurate forecasted monthly sortie schedule results in the effective use of the wing's aircraft and personnel.

To accomplish the comparison, five years of historical aircraft sortie data for five different wings were obtained from Headquarters Tactical Air Command. Four of the years were used with the four time series techniques to forecast the fifth year. The forecasts were then compared to the actual data of the fifth year to determine which technique yielded the best results.

The results of the research indicated that 86% of the time series techniques out performed the current forecasting methodology used in TAC. The best performance of the time series techniques was the modified moving average which, for one wing, was 81% more accurate.

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I. Introduction

This research compares four time series forecasting techniques to the current method used for determining the monthly sortie flying program in the Tactical Air Command. The first section discusses the historical background that shaped the organizational structure of the maintenance complex. Next, the operational planning cycle is discussed, along with a detailed description of the current method used for determining the monthly sortie program. Then, the role of forecasting in the planning process is discussed. Finally, various forecasting techniques are reviewed.

Background

In 1977, the Tactical Air Command (TAC) initiated a decentralized aircraft maintenance management concept called Combat Oriented Maintenance Organization (COMO). CCMO was the final result of four years of development and testing conducted by TAC. This process began in 1973 with the Yom Kippur War, which attracted the attention of the United States

Air Force. The primary reason was that the Israeli Air Force (IAF), flying the same types of aircraft used by TAC, was able to generate and sustain a remarkably high combat sortie rate (4:269). This was achieved by reducing the time between recovering and launching each aircraft. To accomplish this task, the IAF assigned maintenance specialists to the flight line. The maintenance specialists worked side-by-side with the crew chiefs and performed whatever tasks were necessary to get the aircraft ready for the next combat sortie (4:269). By organizing the maintenance work force in this manner, the IAF maintenance leadership was not hobbled with the problem of determining which individual or specialist could work a particular job, since "everybody did everything" (1:46). Instead, the IAF was able to concentrate on generating a high sortie count.

The ability to generate a high sortie count is particularly important in TAC because tactical fighter squadrons must be able to deploy to different locations and generate high sortie rates. Therefore, the objective of COMO was to provide a tactical aircraft maintenance support structure with the mobility and flexibility to survive in a dispersed environment and sustain combat operations (18:1-1). In accomplishing the objective, TAC reorganized the maintenance complex and decentralized the decision making process.

Headed by the deputy commander for maintenance (DCM), the production elements or squadrons of the maintenance complex were organized into direct and indirect sortie producers. The direct sortie production squadron was named the aircraft generation squadron. The indirect sortie production squadrons were named the component repair and equipment maintenance squadrons (Figure 1).

The aircraft generation squadron was further divided into one or more aircraft maintenance units (AMUs). Each AMU was assigned between

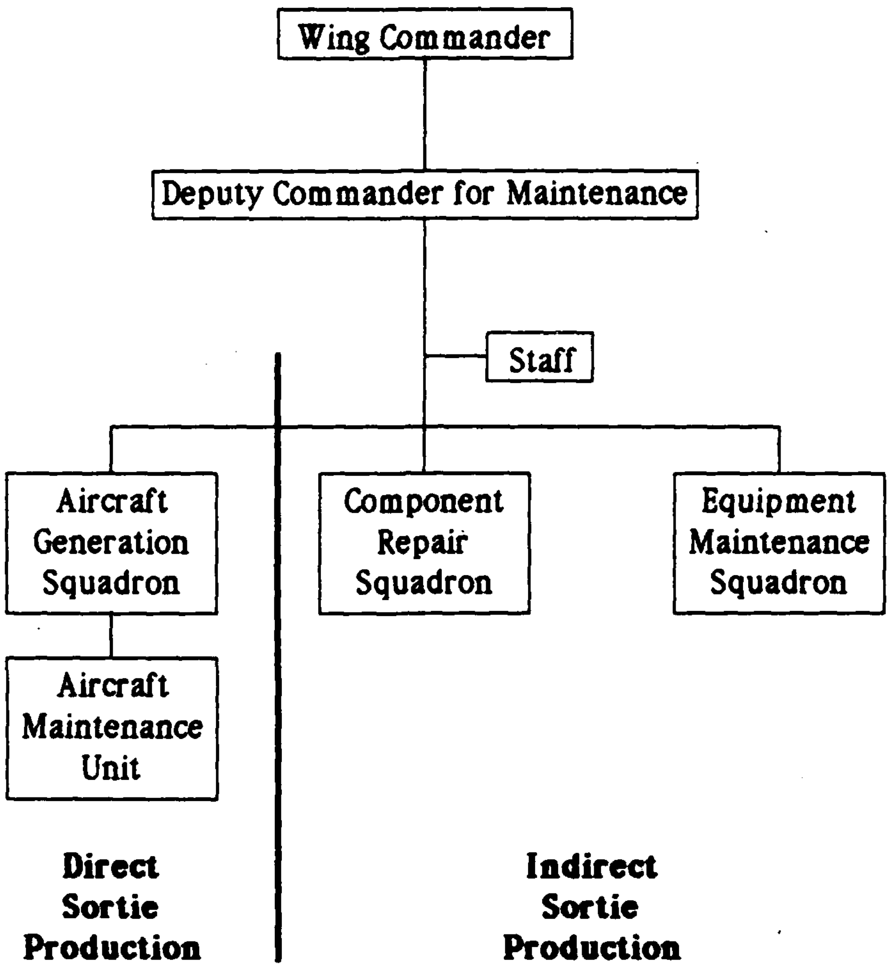


Figure 1. Combat Oriented Maintenance Organization

eighteen and twenty-four aircraft and was dedicated to a tactical fighter squadron. As in the Israeli Air Force, the AMU was provided the production personnel needed to generate sorties. This not only included the crew chiefs and the maintenance specialists, such as hydraulics, electrics, jet engine and avionics specialists, but also the weapons loading personnel. The production personnel were organized into aircraft flights, a specialist flight, a weapons flight, and support elements (18:9-1). In practice, the AMU was assigned responsibility for the launch, service, on-equipment repair, and recovery of its assigned aircraft (18:9-1). On-equipment repair or maintenance denoted the location where the maintenance action will take place. In this situation, on-equipment maintenance is performed on end items such as the aircraft (3:13).

The AMU was designed to operate as a semi-autonomous organization. Even though it had the production personnel assigned to generate sorties, it still relied on the maintenance shops in the indirect sortie producing squadrons to perform off-equipment repairs of unserviceable components. The component repair and equipment maintenance squadrons were given the responsibility to provide off-equipment repair on unserviceable aircraft components within their capability. Off-equipment repair or maintenance referred to those components that are removed from end items or equipment and are generally processed through maintenance or repair shops (3:13). Therefore, a cyclic relationship existed between the direct and indirect sortie producing squadrons. Unserviceable components were removed from the AMU's aircraft and repaired (returned to service) in the component repair or equipment maintenance squadron shops.

Reorganization of the maintenance complex was one step in TAC's emphasis on sortie generation. The second step, and the most important,

was the institutionalization of the decentralized management concept. This concept granted the direct sortie producing squadron the decision making authority to generate the required sortie rate. As Tom Peters, in his book *A Passion For Excellence: The Leadership Difference*, had pointed out - the decision making and management focus has been "shifted from the higher level (input-based) unit--the wing--to the lower level (output-oriented) unit--the squadron" (14:238). With the decision making authority placed at the lowest level, the urgency of a maintenance action can be assessed on the spot and specialist support requested from a work force which is assigned and available in the AMU (5:13). The effect of this change in concept produced the following statistics: "... in 1978, the sortie rate in TAC had been falling for ten years at a compound annual rate of 7.8 percent. From 1978 through 1983, it rose at a compound annual rate of 11.2 percent" (14:48).

Another aspect of decentralized decision making was that the AMU had the management authority over its assigned aircraft. Draft and Steers define management as: "... the process of planning, organizing, directing, and controlling the activities of employees in combination with other organizational resources to accomplish stated organizational objectives" (2:15). Koontz, O'Donnell and Weihrich, in their book *Management*, pointed out that since managerial operations in organizing, directing and controlling are designed to support the accomplishment of organizational objectives, planning logically precedes the execution of all other managerial functions (7:157-158). The planning process is the key function in an organization, because it establishes the objectives or goals necessary for all the elements of the organization to accomplish.

As mentioned above, the AMU was organized as a semi-autonomous sortie producing element with the authority to direct and control its work force. It also has the authority to plan the actions of its work force. This is accomplished by the fact that the AMU has the authority to plan and schedule the use of its aircraft to meet the sortie goals. (18:9-2.1). Since many maintenance tasks are a function of sorties flown. The aircraft schedule developed by the AMU determines the work load for the entire maintenance complex. The sortie schedule impacts the component repair and equipment maintenance squadrons even more, because they provide the support to more than one AMU.

Operational Planning Cycle

The process used to develop a plan and schedule assigned AMU aircraft is called the operations planning cycle. Units that carefully plan their flying and maintenance program and make every effort to meet that plan will do better than units that do not (17:2-1). The maintenance scheduling section in the AMU is tasked with developing a schedule to make the most efficient use of its resources (18:3-13). This is accomplished with a coordinated effort between the maintenance scheduling section and the operations scheduling section of the tactical fighter squadron the AMU is attached. There are three steps in the operations planning cycle. The first step is to determine the monthly sortie goals for the AMU. The number of sorties should be a prime consideration in planning to meet the utilization (UTE) rate goals (18:3-13). The UTE rate is determined at TAC headquarters and assigned to each AMU

at the beginning of the fiscal year. The rate establishes a contract or goal between TAC headquarters and the AMU. The UTE rate signifies the number of sorties each AMU aircraft must fly each month of the fiscal year. For example, if an AMU possesses twenty-four aircraft and is assigned a UTE rate of 20.0, then the AMU's sortie goal for each month in the fiscal year would be 480 sorties. The AMU's annual sortie goal would then be 5,760 sorties.

The next step in the operations planning cycle is for the AMU scheduling section to negotiate with the operations scheduling section to determine the the overall monthly flying schedule, configurations, and launch and recovery patterns to enhance mission accomplishment and improve efficiency (18:3-13). There are two primary considerations in this step that affect the monthly sortie goals negotiated between the two scheduling sections: (1) number of operational and maintenance (O&M) days in each month and (2) the weather or seasonal conditions for each month. O&M days signifies the actual number of work days in each month to meet the sortie goal. Weekends and holidays are excluded from the month to determine the number of O&M days. For example, February has the fewest O&M days with 19, while August has the most O&M days with 23.

The monthly number of O&M days are then considered in light of seasonal conditions. During winter season, the days are shorter and the weather is often less suited for flying. Conversely, during the summer the days are longer the weather is more suited for flying. Since the schedule must make the most efficient use of resources, the two scheduling sections develop monthly sortie goals which may be lower or higher than the assigned UTE. For example, during February the UTE rate might be as low as 16, which yields a monthly sortie goal of 384 sorties; and for August the UTE

rate might be as high as 24, with a sortie goal 576 sorties. The sortie goals for each month must sum the total fiscal year sortie goal of 5,760 sorties.

The final step in the operations planning cycle is to forecast the monthly sortie schedule. The monthly sortie schedule is a combination of the sortie goal and a calculated attrition factor (18:3-14). An attrition factor is used to compensate for lost sorties or deviations from the number of monthly scheduled sorties that occurred in the past (17:A1-1). The attrition factor must be reasonable, since the maintenance work load and capability are directly affected by the added sorties (18:3-14). To calculate the attrition factor, an understanding of deviations is needed.

Flying Schedule Deviations. Deviations are defined as a departure from the monthly sortie schedule (17:A2-1). They are recorded for one of the following reasons:

1. Maintenance deviations result from aircraft discrepancies, unscheduled maintenance, or from an action taken for maintenance considerations.
2. Supply deviations result from a partially mission capable supply (PMCS) or not mission capable supply (NMCS) condition or for late supply or petroleum oil lubricant (POL) delivery.
3. Operations deviations result from an operational requirement or consideration.
4. Higher headquarters deviations result from a higher headquarters taskings.
5. Weather deviations are recorded for aircraft that takeoff early, late, abort, or are added or deleted due to weather conditions.
6. Sympathy deviations occur when a flight of two or more aircraft, under the command of a flight leader or instructor pilot, are deleted, aborted, or late due to a deletion, abort, or delay of one of the aircraft in the flight or a supporting flight.

7. Air traffic control deviations result from air traffic control problems (for example, flight clearance delays, tower communication failure, conflicting air traffic, runway change, or runway closure).

8. Other deviations result from the following:

a. Malfunctions, failures, or necessary adjustments to equipment undergoing tests or evaluations associated with OT&E, DT&E, or IOT&E installed on or in CB-coded aircraft.

b. The unit commander is authorized to cancel all or a portion of the printed schedule during the last five O&M days of the month provided the commander is reasonably assured that the monthly sortie program will be achieved early. Additionally, the commander may cancel all or a part of any one O&M day during the month as a reward for achieving the sortie program over the previous month.

c. Unusual circumstances not covered by the above definitions may use this code. Examples of unusual circumstances include bird strikes, overstressing the aircraft or damage during air refueling [17:3-1].

These eight types of deviations are divided into two categories: chargeable and nonchargeable. The chargeable deviations are generally described as those within the control of local management (17:3-2). The following is a list of chargeable deviations:

1. Operations deviations from the weekly schedule.

2. Aborts:

a. Ground aborts:

(1) If an aborted aircraft is replaced by a spare within 2 hours and can meet the mission requirements, the original aircraft will be charged as a ground abort.

(2) If an aborted aircraft is launched on the originally scheduled mission within 2 hours after the original scheduled takeoff time, the aircraft will be charged as a late takeoff (provided the line has not already been spared).

(3) Ground/air aborts will not be charged against off-base (cross-country) sorties.

(4) Ground/air aborts will be charged against deployed sorties.

(5) Ground aborts will not be recorded against additions, Functional Check Flights (FCF) or Operational Check Flights (OCF).

b. Air aborts. An air abort is considered as a sortie flown when reporting the number of total sorties flown. Air aborts will be coded

in the agency or condition that causes the aborted mission. An air abort will not be recorded when malfunctions occur during the "Before Takeoff Checklist" portion of helicopter sorties.

3. Additions will be recorded against the agency that requested the additional sortie(s). FCFs and OCFs are not additions. These sorties will be considered flown as scheduled.
4. All maintenance deletions that are not replaced by a spare interchanged with another aircraft on the daily schedule.
5. Early and late takeoffs that are caused by maintenance, supply, or operations. If the printed tail number is deleted and replaced with a spare that takes off late (within the 2 hour limit), only the deletion and use of the spare is recorded, not the late takeoff.
6. All supply deviations that result from a filled requisition for which the supply delivery time exceeded the allowable standard in AFM 67-1 and was not replaced by a spare.
7. Late delivery of POL which directly results in a deviation [17:3-2].

On the other hand, nonchargeable deviations are attributed to circumstances or factors that are not within the local control (17:3-2). Nonchargeable deviations are described as the following:

1. All higher headquarter deviations.
2. All weather deviations.
3. All sympathy deviations.
4. All air traffic control deviations.
5. All deviations recorded to "Other."
6. All deletions resulting from a verified NMCS condition.
7. Ground aborts that are attributed to weather, ATC, sympathy, or higher headquarters [17:3-2].

Attrition Factor. The attrition factor for a given month is then based on the number of deviations that has occurred in the past for that month. The type of deviations used to calculate the attrition factor are limited to weather, air traffic, sympathy, other, and higher headquarters deviations (17:A1-1). These deviations are considered nonchargeable and therefore are

nonunit controlled factors. The attrition factor will be computed by month for the entire fiscal year. When calculating the attrition factor, AMUs are to use as much historical data as required to ensure seasonal variations are considered (17:A1-1).

To calculate the attrition factor for February, the AMU would review the available historical records for the month to determine the number of nonchargeable deviations that occurred in the past. Then it would calculate the percentage of nonchargeable deviations by type. The attrition factor is the summation of all nonchargeable deviations. For example, the attrition factor for February might look something like this:

	Weather	.08
	Air Traffic	.00
	Sympathy	.01
	Higher Headquarter	.01
	Other	.02
Total	Attrition Factor	.12

The historical data for February indicate that eight percent of the scheduled sorties were recorded as nonchargeable weather deviations, one percent were sympathy deviations, etc. The attrition factor for February would then be .12 or 12%.

Once the attrition factor has been calculated for each month, then the forecasted number of monthly scheduled sorties can be determined. This is accomplished by dividing the monthly sortie goal by the difference of the attrition factor from 1.00 (17:A1-1). For example, the number of scheduled sorties for February would be:

Monthly Sortie Goal	384
Attrition Rate (1.00 - .12)	.88
Monthly Sorties Schedule	436

Thus, given the twelve percent attrition factor for February, it will require that 436 sorties be scheduled to achieve the goal of 384 sorties.

In summary, the operations planning cycle consisted of determining the monthly sortie goal from the UTE rate assigned by TAC headquarters; adjusting the monthly goals for O&M days and seasonal conditions for each month; and finally forecasting the monthly sortie schedule by including a calculated attrition factor. The three steps of the operations planning cycle are accomplished for each month of the fiscal year.

Scheduling is critically important since the number of monthly scheduled sorties determines the work load for the entire maintenance complex. Maintenance should be directed toward using equipment as scheduled and completing maintenance actions as planned (18:A3-4). A key aspect of the maintenance manager's planning responsibility is to properly schedule work center personnel to meet the requirements of the forecasted monthly sortie schedule. The projected work center personnel capacity can then be based on the scheduled aircraft sorties, aircraft flying hours or equipment operating hours, whichever has the most impact on the work center (18:A3-4). Work center personnel capacities throughout the maintenance complex can be projected and compared to the forecasted monthly sortie schedule. Each AMU would determine its projected work center personnel capacity based on the number of scheduled sorties for the AMU. The component repair and equipment maintenance squadrons would determine their work center personnel requirements based on the total number of scheduled sorties or the total aircraft flying hours in the maintenance complex.

Projected work center personnel capacities are based on past performance. In some cases, a change in the mission or equipment might not be reflected in the past performance. Therefore, the projected capacity must be based on the applied knowledge of the changes. For example, if an

aircraft modification required an additional two hours of direct labor a day per person for a work center, then the maintenance manager would add the additional hours to the historical data. This adjustment is required to avoid underestimating work center personnel capacity requirements.

Work Center Personnel Capacity

The first step in determining the projected work center personnel capacity is to identify the past number of direct productive man-hours of the work center and the number of sorties during a given period. Then, calculate a man-hours expended by sortie (18:A3-4). For example, an aircraft flight in an AMU expended a total of 34,580 actual man-hours in support of 2,880 sorties for the past six months. Then the man-hour per sortie performance of the aircraft flight would be:

32,580 man-hours/2,880 sorties = 11.31 man-hours per sortie.

Next, determine the work center's direct labor utilization rate. The direct labor utilization rate is obtained by dividing the direct productive man-hours by the assigned man-hours (18:A3-5). The assigned man-hours is calculated for same period of time. For example, thirty-three technicians were assigned to the aircraft flight for the past six months. That equates to 264 man-hours per work day or 33,264 man-hours for 126 work days (six months). By dividing 32,850 direct productive man-hours by 33,264 assigned man-hours, a direct labor utilization rate of .99 or 99 percent is obtained.

Finally, the number of sorties the work center personnel are capable of supporting is obtained by multiplying the projected number of assigned

technicians for the month by the number of O&M days for the month, by the number of duty hours per day, by the labor utilization rate, and then dividing the product by the man-hour per sortie rate (18:A3-5). For the aircraft flight with 33 projected technicians for the month of February, it is projected that the flight is capable of supporting 439 sorties.

(33 Technicians X 19 days X 8 hrs X .99 utilization rate)/11.31 hrs - 439

The number of sorties a work center is capable of supporting will vary by work center. The key is to identify the projected work center capacity for a given month and compare it to the forecasted monthly sortie schedule. If the projection indicates fewer sorties can be supported than scheduled, then the maintenance manager must make adjustments within the work center. These adjustments might include extending the work center's duty hours or requesting additional technicians from other organizations.

Forecasting

The planning process used by the AMU in forecasting the number of monthly scheduled sorties must be as accurate as possible for the efficient use of the resources in the maintenance complex. Makridakis and Wheelwright defined the planning process as a "well thought-out set of decisions and actions that when followed ensure that the organization in the future will be affected by its environment in a manner consistent with its goals and objectives" (9:533). A key aspect of decision making is being able to predict the circumstances surrounding individual decision situations (20:20). Therefore, planning is concerned with projecting the future course of actions for an organization. This is also true of forecasting. In the past,

forecasting was considered a technical, primarily statistical, discipline. Today however, forecasting has broadened to include planning and decision making issues (20:1). "Forecasting can provide management with an educated idea of what is going to happen in the future" (4:449). Forecasting can reduce the risk in decision making by accurately predicting the future (13:1). Because both forecasting and planning concern themselves with the future, it is important to integrate these two functions within the organization (9:533-534). By including more accurate forecasting techniques in the planning process more accurate predictions of the future can be accomplished for the organization.

Forecasting Techniques

In the past decade there has been a rapid growth in forecasting techniques. In part this is due to the adoption of the computer (13:3). The types of forecasting techniques and their use in predicting future events vary among different authors. However, they generally fall into two categories: qualitative and quantitative.

Qualitative Forecasting Techniques. Qualitative forecasting techniques forecast changes in a basic pattern as well as the pattern itself. This is primarily used when insufficient historical data are available to form a quantitative prediction. Clark in the introduction of his book *Profiles of the Future* describes the task faced in making a qualitative forecast:

> (The forecast) does not try to describe the future, but to define the boundaries within which the possible futures must lie. If we regard the ages which stretch ahead of us as an unmapped and unexplored country, what (one) is attempting to do is to survey its frontiers and to get some idea of its extent. The detailed geography of the interior must remain unknown until we reach it [20:268].

Since the historical data are not available or are limited, qualitative forecasts are based on the subjective judgement of experts, individuals or group of individuals with the best understanding of the situation. Caution must be taken with qualitative forecasting techniques, because the forecast reflects the experience and concerns of the expert. Variations in the forecast can occur among different experts on a single issue. Qualitative forecasting techniques are generally divided into two general categories: exploratory and normative.

Exploratory methods begin with the past and present as their starting point and move towards the future in a heuristic manner, often by looking at all available possibilities (9:10). The Delphi technique, s-curve fitting, and analogies are a few of the more commonly used exploratory methods.

The Delphi technique was developed at the Rand Corporation. It is the most commonly used of the qualitative techniques. This technique attempts to obtain a reliable consensus of opinion on a future forecast from a group of experts. The methodology used in the technique minimizes the undesirable aspects of group interaction. This is accomplished by keeping the experts apart; therefore, reducing the opportunity for debate and individual influence. Helmer and Rescher, two of the main developers of this approach, describe the Delphi approach as follows:

> The Delphi technique eliminates committee activity altogether thus further reducing the influence of certain psychological factors, such as specious persuasion, the unwillingness to abandon publicly expressed opinions, and the bandwagon effect of majority opinion. This

technique replaces direct debate by a carefully designed program of sequential individual interrogations (best conducted by questionnaires), interspersed with information and opinion feedback derived by computer consensus from the earlier parts of the program. Some of the questions directed at respondents may, for instance, inquire into the "reasons" for previous expressed opinions and a collection of such reasons may then be presented to each respondent in the group, together with an invitation to reconsider and possibly revise his or her earlier estimates [9:498].

S-curve techniques are mostly used in forecasting new products. This technique uses the basic pattern for the growth of demand for a particular product over time (12:83-84). The lower portion of the s-curve depicts the acceptance and growth of the product; the center portion reflects the rapid market growth of the product; and the upper portion of the curve indicates the consumer demand of the product. In most cases, only a few data points are available for the expert to forecast with; therefore, the shape of the s-curve is determined by the expert's experience.

Analogies are used as a qualitative technique to compare patterns in various technologies and the environment to forecast future progress and developments. Analogies are mostly used in those situations where no data are available and no other method is suitable. The expert can use intuitive judgement when forecasting the future from an analogous situation or event.

Normative methods start with the future by determining future goals and objectives, then work backwards to see if these can be achieved, given the constraints, resources, and technologies available (9:10). Two normative methods are the relevance tree and system analysis.

The relevance tree is based on decision theory. It is used to assess different technologies needed to achieve the desired of future goal. The relevance tree is formed by first identifying the objective or goal of the

program. Then branched down from the goal are the various levels of objectives required to attain the goal. These are identified by experts based on their assessment of the relationship between the objective and the subobjectives. The branches can form many levels of methods, until the technologies for goal achievement are identified. A panel of experts then assigns a value on the relevance or importance of each element identified in the tree. The relevance values are multiplied by the individual relevance values in the line above it. The product constitutes the relevance factor for that branch in the tree.

The system analysis approach is concerned with predicting the future behavior of an organization or system. This is accomplished by analyzing the pattern of interactions between the various components within the organization. The purpose is to develop a model of the system. When analyzing the components, the goals and objectives of the organization must be considered, rather than the individual components. Based on the patterns identified, alternative future patterns can be recommended to aid the organization in achieving its goal.

Quantitative Forecasting Techniques. Quantitative techniques differ from qualitative techniques because the prediction of the future is based on known historical data. The historical data are applied to a set of rules or equations. These rules or equations identify patterns in the historical data and then project the pattern to the future. Three assumptions are made when using quantitative techniques: (1) there is information about the past; (2) the information can be quantified in the form of data; and (3) it can be assumed that the pattern of the past will continue into the future (9:7).

Quantitative techniques have become a more accepted form of predicting the future. According to Wheelwright and Makridarkis:

> Quantitative forecasting techniques have gained wide acceptance over the last few decades for at least three reasons. One has been that they have developed a record of accuracy as a means of preparing forecasts. Thus managers have placed increasing confidence in them as an aid to decision making. A second important factor has been the development and adoption of computers. The computer can be used not only to make the many computations that quantitative forecasting methods require but also to store historical data and then retrieve that data rapidly and efficiently when it is needed for the preparation of a new forecast. The last reason is that quantitative forecasts are, generally, much cheaper to obtain than any of the available alternatives [20:5].

Quantitative forecasting techniques are generally divided into two categories: time series and causal. A time series is a set of numbers that measures the status of some ongoing process or activity over time (13:4). Lt Col Christensen, in the book *Military Logistics*, pointed out that "much of what we deal with in the DoD fits this pattern. We collect monthly flying hours (or sorties), daily demand data, monthly maintenance hours, yearly vehicle miles and more" (4:445).

Time series are observations of events measured in periods of years, months, weeks, or days. Each period in the time series is of equal length. An important aspect of time series data is that the historical data are arranged in sequential order, from the oldest to the latest observation. Data must be observed or recorded for each time period. In order for the time series technique to predict the future accurately, the method of measuring the time series must be consistent. Moving average and exponential smoothing are two types of time series techniques.

The moving average technique is a simply the average of a set of values for a times series. The average is then used as the forecast for the next period. The number of values in a set is determined by the forecaster and remains constant. With the moving average technique, the larger the number of values in the set, the greater the smoothing effect on the forecast. The moving average technique is represented in the following way:

$$F_t = (Y_{t-1} + Y_{t-2} + Y_{t-3} + \ldots + Y_{t-n})/n;$$

where:

F_t = the forecast value of Y for time t,

Y_t = the actual value of Y at time t,

n = the number of values included in the average [20:59-60].

Exponential smoothing techniques are similar to moving average techniques. However, they use a weighted value, alpha, to smooth the past values of the data in the forecast. The advantage of the technique is that it greatly reduces the need to store large data sets. All that is needed for an exponential smoothing technique is the last observed value, the last forecast value, and a value for alpha. Alpha can be set at any value between one and zero; however, it is unusual to have an alpha value greater than .3. The forecaster determines the value of alpha. As the value of alpha increases, the more significance is placed on the last observed value and the less smoothing occurs in the forecast. Conversely, as the value of alpha decreases, less significance is placed on the last observed value and more smoothing occurs in the forecast. Therefore, the forecaster must chose the value of alpha that best forecasts the next period. The tradeoff is between responsiveness to change and stability of the forecast. The exponential smoothing technique is calculated using the following formula:

$$\mathit{Y}_t = \alpha Y_{t-1} + (1-\alpha)\mathit{Y}_{t-1}$$

where:

Y_t = the forecast value of Y for time t,

Y_t = the actual value of Y at time t,

α = set of weights with $0 <= \alpha <= 1$ [4:441].

Causal techniques are used to forecast cause-effect relationships. In this case the dependent variable to be forecasted is a function of one or more independent variables. This technique determines the form of the relationship and uses it to forecast the future value of the dependent variable. Causal techniques are represented in two ways. The first indicates a single cause-effect relationship and the second indicates multiple cause-effect relationships. Simple linear regression models are used to define single cause-effect relationships and can be expressed as:

$$Y = a + bx$$

where:

Y = a series of historical dependent variable values,

X = a corresponding series of independent variable values,

a = the parameter value which is the intercept for the Y-axis when X takes on a value of zero,

b = the parameter value associated with the independent variable, also the slope of the two dimensional line [4:443].

Whereas, multiple regression models are used when there are more than one independent variable and are expressed as:

$$Y_i = B_0 + B_1X_{1i} + B_2X_{2i} + \ldots + B_kX_{ki} + e_i$$

where:

Y_i = the i^{th} observation of the dependent variable,

X_{ki} = the i^{th} observed value of 1 to k independent variables,

B_k = the parameter values essential to show a solution to the regression,

e_i = error term [4:443].

Research Question

Since the number of scheduled sorties each month affects the work load throughout the maintenance complex, it follows logically that the forecast for the monthly sorties should be as accurate as possible. The focus of this research is to compare various quantitative forecasting techniques to the current methodology used in the operational planning cycle.

The research question then is which quantitative forecasting technique will produce the most accurate forecast?

II. Methodology

This research compared time series techniques to the current forecasting methodology used in the Tactical Air Command to determine the required number of monthly scheduled sorties needed to meet the aircraft sortie goal. To accomplish the comparison, five years of historical sortie data were obtained from TAC for five randomly chosen tactical fighter wings. Since the historical sortie data for each wing varied for the number of aircraft and the aircraft utilization rate, adjustments will be made to the historical data to standardize the different time periods. Next, four time series techniques are used forecast the sortie rate. Two diagnostic checks will then be selected to determine how well the techniques model the historical data. Finally, the accuracy of the forecasting technique will be measured by the mean squared error and the results compared to determine the most accurate technique.

Selecting the Sample Wings

There are fourteen tactical fighter wings in TAC -- two F-4 wings, three F-15 wings, five F-16 wings, two F-111 wings and two A-10 wings (15:144). Five wings were randomly chosen for the comparison. Each wing represented one of the five fighter aircraft. The wings chosen were:

1. F-15 -- 1 Tactical Fighter Wing, Langley AFB, VA;
2. F-111 -- 27 Tactical Fighter Wing, Cannon AFB, NM;
3. F-4 -- 37 Tactical Fighter Wing, George AFB, CA;

4. A-10 -- 354 Tactical Fighter Wing, Myrtle Beach AFB, SC; and

5. F-16 -- 388 Tactical Fighter Wing, Hill AFB, UT.

The method used in choosing the wings involved two steps. First, each wing with a similar aircraft was assigned a sequential number; next, a random number table was used to select the wing. For example, for the F-16 wings, the 31 TFW was assigned number one, 347 TFW was assigned two, the 363 TFW was assigned three, the 388 TFW was assigned four, and the 474 TFW was assigned five. The number selected from the random number table was four. Thus, the 388 TFW was chosen.

The Historical Aircraft Sortie Data

Five years of historical sortie data for each wing was obtained from the Reports & Analysis Division, Deputy Chief of Logistics, Headquarters Tactical Air Command. The division gathered the data from the monthly maintenance information logically analyzed and presented (MILAP) report sent out by each wing. "The MILAP report integrates related elements of data from several sources and displays the data in a standard easy-to-read format" (18:5-3). A section of the report records the aircraft sortie information for the entire wing. The data represented fiscal years 1983, 1984, 1985, 1986 and 1987. Tables 1-5 show the historical aircraft sortie data for the five wings.

Month	Fiscal Year 1983		Fiscal Year 1984		Fiscal Year 1985	
	Forcasted Scheduled Sorties	Actual Sorties Flown	Forcasted Scheduled Sorties	Actual Sorties Flown	Forcasted Scheduled Sorties	Actual Sorties Flown
Oct	2237	2054	1861	1740	1696	1547
Nov	1750	1589	1996	2024	1644	1518
Dec	1744	1516	1480	1236	1631	1408
Jan	1921	1487	1797	1519	1991	1644
Feb	1576	1348	1844	1315	1614	1442
Mar	2145	1711	1743	1743	2069	1956
Apr	2535	1873	1794	1741	1900	1745
May	1647	1362	2013	1926	1848	1747
Jun	1902	1785	1637	1726	1940	1706
Jul	1677	1514	1626	1526	1561	1421
Aug	1826	1634	1881	1681	1670	1707
Sep	1334	1132	1327	1202	1284	1311

Month	Fiscal Year 1986		Fiscal Year 1987	
	Forcasted Scheduled Sorties	Actual Sorties Flown	Forcasted Scheduled Sorties	Actual Sorties Flown
Oct	2232	1866	2104	1902
Nov	1509	1497	1525	1317
Dec	1526	1485	1466	1476
Jan	1665	1687	1686	1578
Feb	1765	1454	1678	1481
Mar	1690	1591	1848	1788
Apr	1852	1782	1854	1686
May	1990	1846	1662	1582
Jun	1382	1408	1906	1718
Jul	1847	1696	1851	1721
Aug	1594	1577	1697	1633
Sep	1351	1132	1438	1218

Table 1. A-10 Historical Sortie Data

Month	Fiscal Year 1983		Fiscal Year 1984		Fiscal Year 1985	
	Forcasted Scheduled Sorties	Actual Sorties Flown	Forcasted Scheduled Sorties	Actual Sorties Flown	Forcasted Scheduled Sorties	Actual Sorties Flown
Oct	1966	1563	2463	1906	2615	2231
Nov	2130	1758	2512	1873	2677	2250
Dec	2009	1398	2241	1640	2120	1739
Jan	2184	1558	2451	1719	2356	1687
Feb	1893	1392	2553	1976	2109	1708
Mar	2817	1913	3067	2028	2812	2488
Apr	2451	2184	2674	2158	1837	1650
May	2413	2089	2082	1584	1885	1621
Jun	2497	2120	2656	2272	1860	1628
Jul	2096	1832	2197	1779	1741	1515
Aug	2626	2079	2614	2257	1433	1185
Sep	2114	1745	2738	1856	1628	1195

Month	Fiscal Year 1986		Fiscal Year 1987	
	Forcasted Scheduled Sorties	Actual Sorties Flown	Forcasted Scheduled Sorties	Actual Sorties Flown
Oct	2056	1567	1643	1729
Nov	1498	1176	1420	993
Dec	1930	1565	1642	1561
Jan	1730	1485	1599	1422
Feb	1764	1370	1474	1440
Mar	1798	1590	1658	1450
Apr	1769	1618	1862	1798
May	1553	1486	1518	1400
Jun	1558	1682	1553	1696
Jul	1709	1434	1496	1507
Aug	1582	1318	1480	1367
Sep	1253	991	1142	985

Table 2. F-4 Historical Sortie Data

Month	Fiscal Year 1983		Fiscal Year 1984		Fiscal Year 1985	
	Forcasted Scheduled Sorties	Actual Sorties Flown	Forcasted Scheduled Sorties	Actual Sorties Flown	Forcasted Scheduled Sorties	Actual Sorties Flown
Oct	644	469	2186	2192	2539	2185
Nov	590	450	2893	2114	2713	2344
Dec	703	528	2356	1667	2061	1648
Jan	1166	906	2801	1932	2621	1969
Feb	1157	1024	2632	1967	2222	1963
Mar	1380	1176	2477	2076	2592	2238
Apr	2000	1734	2487	2183	2685	2340
May	2073	1748	2545	2361	2185	2094
Jun	2136	1842	2461	2457	2194	2278
Jul	1878	1699	2152	2208	2144	2014
Aug	2470	1999	2282	2159	2514	2240
Sep	1510	1361	1620	1611	2582	2070

Month	Fiscal Year 1986		Fiscal Year 1987	
	Forcasted Scheduled Sorties	Actual Sorties Flown	Forcasted Scheduled Sorties	Actual Sorties Flown
Oct	2359	2207	2050	1816
Nov	2357	2077	1726	1549
Dec	2091	1521	1615	1421
Jan	2375	2043	1773	1396
Feb	2173	1716	1754	1515
Mar	2564	2094	1875	1599
Apr	2541	2241	1923	1835
May	2460	2150	1642	1376
Jun	2689	2454	1801	1740
Jul	2390	2178	2258	1935
Aug	2072	1894	1839	1742
Sep	1570	1344	1288	1150

Table 3. F-16 Historical Sortie Data

Month	Fiscal Year 1983		Fiscal Year 1984		Fiscal Year 1985	
	Forcasted Scheduled Sorties	Actual Sorties Flown	Forcasted Scheduled Sorties	Actual Sorties Flown	Forcasted Scheduled Sorties	Actual Sorties Flown
Oct	291	260	464	405	537	451
Nov	292	254	521	419	440	390
Dec	342	256	439	327	437	330
Jan	300	246	594	420	460	378
Feb	302	280	452	378	459	336
Mar	300	288	622	495	475	448
Apr	331	275	455	389	468	406
May	275	243	476	423	587	497
Jun	284	257	422	357	453	414
Jul	194	177	465	404	461	414
Aug	306	291	467	412	539	465
Sep	286	255	403	336	302	270

Month	Fiscal Year 1986		Fiscal Year 1987	
	Forcasted Scheduled Sorties	Actual Sorties Flown	Forcasted Scheduled Sorties	Actual Sorties Flown
Oct	519	464	540	474
Nov	465	398	467	399
Dec	446	364	464	346
Jan	461	406	544	428
Feb	490	386	443	393
Mar	499	435	453	416
Apr	623	509	530	465
May	470	405	493	441
Jun	463	370	562	463
Jul	701	544	477	450
Aug	383	294	492	470
Sep	434	393	463	360

Table 4. F-111 Historical Sortie Data

Month	Fiscal Year 1983		Fiscal Year 1984		Fiscal Year 1985	
	Forcasted Scheduled Sorties	Actual Sorties Flown	Forcasted Scheduled Sorties	Actual Sorties Flown	Forcasted Scheduled Sorties	Actual Sorties Flown
Oct	1740	1413	1743	1594	2160	1769
Nov	1496	1355	2057	1761	1730	1560
Dec	1863	1581	1785	1541	1546	1367
Jan	1630	1391	1730	1491	1797	1475
Feb	1535	1251	1723	1322	1901	1642
Mar	1733	1484	2085	1623	2493	2318
Apr	1753	1595	1716	1569	1331	1261
May	1706	1501	1841	1645	1739	1610
Jun	1674	1551	1739	1586	1720	1644
Jul	1596	1520	1524	1385	1895	1733
Aug	1833	1613	1968	1713	1727	1602
Sep	1278	1106	1013	998	1376	1235

Month	Fiscal Year 1986		Fiscal Year 1987	
	Forcasted Scheduled Sorties	Actual Sorties Flown	Forcasted Scheduled Sorties	Actual Sorties Flown
Oct	1899	1620	1847	1676
Nov	2127	1728	1418	1173
Dec	1672	1403	1808	1452
Jan	1873	1599	1505	1201
Feb	1827	1314	1489	1199
Mar	1998	1720	1882	1506
Apr	2088	1944	1810	1436
May	1840	1566	1517	1393
Jun	1623	1539	2243	1942
Jul	1745	1639	2098	1985
Aug	1922	1671	1302	1176
Sep	1021	896	1415	1227

Table 5. F-15 Historical Sortie Data

Adjusting the Historical Aircraft Sortie Data

"In many forecasting situations, some preprocessing or adjusting of the data is necessary after they have been collected but before they are used in a quantitative forecasting technique" (9:617). Adjustments to the historical sortie data were made for two reasons. First, the number of aircraft at some wings were not always constant for each fiscal year. Second, the aircraft utilization rate (UTE) for some wings were not constant for each fiscal year. Therefore, to forecast the number of scheduled sorties for the fifth year, the historical sortie data for the previous four years had to be standardized.

For example, the historical sortie data for the F-111 wing indicated that the aircraft UTE rate and the number of aircraft for fiscal year 1983 were 10.7 and 24 respectively; for fiscal year 1984, they were 11.03 and 36; for fiscal year 1985, they were 11.11 and 36; for fiscal year 1986, they were 11.5 and 36. The assigned aircraft UTE rate for fiscal year 1987 was 11.5 and the wing had 36 aircraft for that year. Therefore, the previous fiscal years' historical sortie data were standardized to the forecasted fiscal year 1987.

To standardize the historical sortie data, two steps were used for the adjustment. The first step was to divide the number of aircraft for each previous year by the number of aircraft for the forecasted year. The quotient produced an aircraft ratio. The aircraft ratio was then divided into the actual sorties flown for the previous year. This adjusted the actual sorties flown for the number of aircraft. Next, the UTE rate for each previous year was divided by the UTE rate for the forecasted year. This quotient produced a UTE ratio. The UTE ratio was divided into adjusted sorties in step

one. The final quotient standardized the actual sorties flown for each previous year. Tables 6-24 show the data adjustments for each aircraft by fiscal year. The aircraft and UTE ratio are rounded to the nearest hundredth for presentation only. Calculations of the adjusted sorties flown were made using unrounded numbers.

Selecting the Quantitative Forecasting Techniques

Quantitative forecasting techniques are classified in two general types: time series and causal. Casual techniques were used when there existed a cause-effect relationship between one dependent variable and one or more independent variables. The first step in determining whether to use a causal technique was to determine the cause and effect relationship of the system being forecasted. After reviewing the data, a cause and effect relationship was not identified between the number of scheduled sorties and the month in which they were scheduled. In other words, the number of sorties scheduled for a particular month was not a function of the month. Therefore, causal quantitative forecasting techniques were not used in this research.

Time series techniques were used when there existed observations of past events measured in equal periods of time, as in the case with the historical sortie data. The pattern formed from the observations was then used to predict future time periods. The first step in using a time series technique was to graph the historical sortie data for each wing. Figures 2-6 are graphical representations of the adjusted historical sortie data. The graphs were used as an aid in identifying the patterns formed by the data.

Month	Actual Sorties Flown	Aircraft Ratio	Adjusted Aircraft	UTE Ratio	Adjusted Sorties Flown
Oct	2054	1.00	2054	1.00	2054
Nov	1589	1.00	1589	1.00	1589
Dec	1516	1.00	1516	1.00	1516
Jan	1487	1.00	1487	1.00	1487
Feb	1348	1.00	1348	1.00	1348
Mar	1711	1.00	1711	1.00	1711
Apr	1873	1.00	1873	1.00	1873
May	1362	1.00	1362	1.00	1362
Jun	1785	1.00	1785	1.00	1785
Jul	1514	1.00	1514	1.00	1514
Aug	1634	1.00	1634	1.00	1634
Sep	1132	1.00	1132	1.00	1132
Sum	19005		19008		19008
Mean	1584		1584		1584
Aircraft	72		72		72
Annual UTE	22.00		22.00		22.00

Table 6. Adjustments to A-10 FY 1983 Actual Sorties Flown

Month	Actual Sorties Flown	Aircraft Ratio	Adjusted Aircraft	UTE Ratio	Adjusted Sorties Flown
Oct	1740	1.01	1720	1.01	1707
Nov	2024	1.01	2001	1.01	1985
Dec	1236	1.01	1222	1.01	1212
Jan	1519	1.01	1501	1.01	1490
Feb	1315	1.01	1300	1.01	1290
Mar	1743	1.01	1723	1.01	1710
Apr	1741	1.01	1721	1.01	1708
May	1926	1.01	1904	1.01	1889
Jun	1726	1.01	1706	1.01	1693
Jul	1526	1.01	1508	1.01	1497
Aug	1681	1.01	1662	1.01	1649
Sep	1202	1.01	1188	1.01	1179
Sum	19379		19155		19008
Mean	1615		1596		1584
Aircraft	73		72		72
Annual UTE	22.17		22.17		22.00

Table 7. Adjustments to A-10 FY 1984 Actual Sorties Flown

Month	Actual Sorties Flown	Aircraft Ratio	Adjusted Aircraft	UTE Ratio	Adjusted Sorties Flown
Oct	1547	1.00	1547	1.01	1535
Nov	1518	1.00	1518	1.01	1507
Dec	1408	1.00	1408	1.01	1397
Jan	1644	1.00	1644	1.01	1632
Feb	1442	1.00	1442	1.01	1431
Mar	1956	1.00	1956	1.01	1941
Apr	1745	1.00	1745	1.01	1732
May	1747	1.00	1747	1.01	1734
Jun	1706	1.00	1706	1.01	1693
Jul	1421	1.00	1421	1.01	1410
Aug	1707	1.00	1707	1.01	1694
Sep	1311	1.00	1311	1.01	1301
Sum	19152		19155		19008
Mean	1596		1596		1584
Aircraft	72		72		72
Annual UTE	22.17		22.17		22.00

Table 8. Adjustments to A-10 FY 1985 Actual Sorties Flown

Month	Actual Sorties Flown	Aircraft Ratio	Adjusted Aircraft	UTE Ratio	Adjusted Sorties Flown
Oct	1866	1.00	1866	1.00	1865
Nov	1497	1.00	1497	1.00	1496
Dec	1485	1.00	1485	1.00	1484
Jan	1687	1.00	1687	1.00	1686
Feb	1454	1.00	1454	1.00	1453
Mar	1591	1.00	1591	1.00	1590
Apr	1782	1.00	1782	1.00	1781
May	1846	1.00	1846	1.00	1845
Jun	1408	1.00	1408	1.00	1407
Jul	1696	1.00	1696	1.00	1695
Aug	1577	1.00	1577	1.00	1576
Sep	1132	1.00	1132	1.00	1131
Sum	19021		19025		19008
Mean	1585		1585		1584
Aircraft	72		72		72
Annual UTE	22.02		22.02		22.00

Table 9. Adjustments to A-10 FY 1986 Actual Sorties Flown

Month	Actual Sorties Flown	Aircraft Ratio	Adjusted Aircraft	UTE Ratio	Adjusted Sorties Flown
Oct	1563	1.30	1199	0.96	1249
Nov	1758	1.30	1349	0.96	1404
Dec	1398	1.30	1073	0.96	1117
Jan	1558	1.30	1195	0.96	1245
Feb	1392	1.30	1068	0.96	1112
Mar	1913	1.30	1468	0.96	1528
Apr	2184	1.30	1676	0.96	1745
May	2089	1.30	1603	0.96	1669
Jun	2120	1.30	1627	0.96	1694
Jul	1832	1.30	1406	0.96	1463
Aug	2079	1.30	1595	0.96	1661
Sep	1745	1.30	1339	0.96	1394
Sum	21631		16597		17280
Mean	1803		1383		1440
Aircraft	94		72		72
Annual UTE	19.21		19.21		20.00

Table 10. Adjustments to F-4 FY 1983 Actual Sorties Flown

Month	Actual Sorties Flown	Aircraft Ratio	Adjusted Aircraft	UTE Ratio	Adjusted Sorties Flown
Oct	1906	1.33	1430	1.00	1429
Nov	1873	1.33	1405	1.00	1404
Dec	1640	1.33	1230	1.00	1230
Jan	1719	1.33	1289	1.00	1289
Feb	1976	1.33	1482	1.00	1481
Mar	2028	1.33	1521	1.00	1520
Apr	2158	1.33	1619	1.00	1618
May	1584	1.33	1188	1.00	1188
Jun	2272	1.33	1704	1.00	1703
Jul	1779	1.33	1334	1.00	1334
Aug	2257	1.33	1693	1.00	1692
Sep	1856	1.33	1392	1.00	1392
Sum	23048		17289		17280
Mean	1921		1441		1440
Aircraft	96		72		72
Annual UTE	20.01		20.01		20.00

Table 11. Adjustments to F-4 FY 1984 Actual Sorties Flown

Month	Actual Sorties Flown	Aircraft Ratio	Adjusted Aircraft	UTE Ratio	Adjusted Sorties Flown
Oct	2231	1.19	1868	1.01	1845
Nov	2250	1.19	1884	1.01	1861
Dec	1739	1.19	1456	1.01	1438
Jan	1687	1.19	1412	1.01	1395
Feb	1708	1.19	1430	1.01	1412
Mar	2488	1.19	2083	1.01	2057
Apr	1650	1.19	1381	1.01	1364
May	1621	1.19	1357	1.01	1340
Jun	1628	1.19	1363	1.01	1346
Jul	1515	1.19	1268	1.01	1253
Aug	1185	1.19	992	1.01	980
Sep	1195	1.19	1001	1.01	988
Sum	20897		17496		17280
Mean	1741		1458		1440
Aircraft	86		72		72
Annual UTE	20.25		20.25		20.00

Table 12. Adjustments to F-4 FY 1985 Actual Sorties Flown

Month	Actual Sorties Flown	Aircraft Ratio	Adjusted Aircraft	UTE Ratio	Adjusted Sorties Flown
Oct	1567	1.00	1567	1.00	1567
Nov	1176	1.00	1176	1.00	1176
Dec	1565	1.00	1565	1.00	1565
Jan	1485	1.00	1485	1.00	1485
Feb	1370	1.00	1370	1.00	1370
Mar	1590	1.00	1590	1.00	1590
Apr	1618	1.00	1618	1.00	1618
May	1486	1.00	1486	1.00	1486
Jun	1682	1.00	1682	1.00	1682
Jul	1434	1.00	1434	1.00	1434
Aug	1318	1.00	1318	1.00	1318
Sep	991	1.00	991	1.00	991
Sum	17282		17280		17280
Mean	1440		1440		1440
Aircraft	72		72		72
Annual UTE	20.00		20.00		20.00

Table 13. Adjustments to F-4 FY 1986 Actual Sorties Flown

Month	Actual Sorties Flown	Aircraft Ratio	Adjusted Aircraft	UTE Rate	Adjusted Sorties Flown
Oct	469	0.78	598	1.05	570
Nov	450	0.78	573	1.05	547
Dec	528	0.78	673	1.05	641
Jan	906	0.78	1155	1.05	1101
Feb	1024	0.78	1305	1.05	1244
Mar	1176	0.78	1499	1.05	1429
Apr	1734	0.78	2210	1.05	2106
May	1748	0.78	2228	1.05	2123
Jun	1842	0.78	2347	1.05	2238
Jul	1699	0.78	2165	1.05	2064
Aug	1999	0.78	2547	1.05	2428
Sep	1361	0.78	1734	1.05	1653
Sum	14936		19034		18144
Mean	1245		1586		1512
Aircraft	56		72		72
Annual UTE	22.03		22.03		21.00

Table 14. Adjustments to F-16 FY 1983 Actual Sorties Flown

Month	Actual Sorties Flown	Aircraft Ratio	Adjusted Aircraft	UTE Rate	Adjusted Sorties Flown
Oct	2192	1.32	1659	1.04	1596
Nov	2114	1.32	1600	1.04	1539
Dec	1667	1.32	1261	1.04	1213
Jan	1932	1.32	1462	1.04	1406
Feb	1967	1.32	1488	1.04	1432
Mar	2076	1.32	1571	1.04	1511
Apr	2183	1.32	1652	1.04	1589
May	2361	1.32	1786	1.04	1719
Jun	2457	1.32	1859	1.04	1788
Jul	2208	1.32	1671	1.04	1607
Aug	2159	1.32	1634	1.04	1572
Sep	1611	1.32	1219	1.04	1173
Sum	24927		18861		18144
Mean	2077		1572		1512
Aircraft	95		72		72
Annual UTE	21.83		21.83		21.00

Table 15. Adjustments to F-16 FY 1984 Actual Sorties Flown

Month	Actual Sorties Flown	Aircraft Ratio	Adjusted Aircraft	UTE Rate	Adjusted Sorties Flown
Oct	2185	1.33	1638	1.05	1562
Nov	2344	1.33	1758	1.05	1676
Dec	1648	1.33	1236	1.05	1178
Jan	1969	1.33	1476	1.05	1407
Feb	1963	1.33	1472	1.05	1403
Mar	2238	1.33	1678	1.05	1600
Apr	2340	1.33	1755	1.05	1673
May	2094	1.33	1570	1.05	1497
Jun	2278	1.33	1708	1.05	1628
Jul	2014	1.33	1510	1.05	1440
Aug	2240	1.33	1680	1.05	1601
Sep	2070	1.33	1552	1.05	1480
Sum	25383		19034		18144
Mean	2115		1586		1512
Aircraft	96		72		72
Annual UTE	22.03		22.03		21.00

Table 16. Adjustments to F-16 FY 1985 Actual Sorties Flown

Month	Actual Sorties Flown	Aircraft Ratio	Adjusted Aircraft	UTE Rate	Adjusted Sorties Flown
Oct	2207	1.27	1736	1.04	1674
Nov	2077	1.27	1634	1.04	1576
Dec	1521	1.27	1197	1.04	1154
Jan	2043	1.27	1607	1.04	1550
Feb	1716	1.27	1350	1.04	1302
Mar	2094	1.27	1647	1.04	1588
Apr	2241	1.27	1763	1.04	1700
May	2150	1.27	1691	1.04	1631
Jun	2454	1.27	1931	1.04	1862
Jul	2178	1.27	1714	1.04	1652
Aug	1894	1.27	1490	1.04	1437
Sep	1344	1.27	1057	1.04	1020
Sum	23919		18818		18144
Mean	1993		1568		1512
Aircraft	92		72		72
Annual UTE	21.78		21.78		21.00

Table 17. Adjustments to F-16 FY 1986 Actual Sorties Flown

Month	Actual Sorties Flown	Aircraft Ratio	Adjusted Aircraft	UTE Ratio	Adjusted Sorties Flown
Oct	260	0.67	390	0.93	419
Nov	254	0.67	381	0.93	409
Dec	256	0.67	384	0.93	413
Jan	246	0.67	369	0.93	397
Feb	280	0.67	420	0.93	451
Mar	288	0.67	432	0.93	464
Apr	275	0.67	412	0.93	443
May	243	0.67	364	0.93	392
Jun	257	0.67	385	0.93	414
Jul	177	0.67	265	0.93	285
Aug	291	0.67	436	0.93	469
Sep	255	0.67	382	0.93	411
Sum	3082		4622		4968
Mean	257		385		414
Aircraft	24		36		36
Annual UTE	10.70		10.70		11.50

Table 18. Adjustments to F-111 FY 1983 Actual Sorties Flown

Month	Actual Sorties Flown	Aircraft Ratio	Adjusted Aircraft	UTE Ratio	Adjusted Sorties Flown
Oct	405	1.00	405	0.96	422
Nov	419	1.00	419	0.96	437
Dec	327	1.00	327	0.96	341
Jan	420	1.00	420	0.96	438
Feb	378	1.00	378	0.96	394
Mar	495	1.00	495	0.96	516
Apr	389	1.00	389	0.96	406
May	423	1.00	423	0.96	441
Jun	357	1.00	357	0.96	372
Jul	404	1.00	404	0.96	421
Aug	412	1.00	412	0.96	430
Sep	336	1.00	336	0.96	350
Sum	4765		4765		4968
Mean	397		397		414
Aircraft	36		36		36
Annual UTE	11.03		11.03		11.50

Table 19. Adjustments to F-111 FY 1984 Actual Sorties Flown

Month	Actual Sorties Flown	Aircraft Ratio	Adjusted Aircraft	UTE Ratio	Adjusted Sorties Flown
Oct	451	1.00	451	0.97	467
Nov	390	1.00	390	0.97	404
Dec	330	1.00	330	0.97	342
Jan	378	1.00	378	0.97	391
Feb	336	1.00	336	0.97	348
Mar	448	1.00	448	0.97	464
Apr	406	1.00	406	0.97	420
May	497	1.00	497	0.97	515
Jun	414	1.00	414	0.97	429
Jul	414	1.00	414	0.97	429
Aug	465	1.00	465	0.97	481
Sep	270	1.00	270	0.97	280
Sum	4799		4800		4968
Mean	400		400		414
Aircraft	36		36		36
Annual UTE	11.11		11.11		11.50

Table 20. Adjustments to F-111 FY 1985 Actual Sorties Flown

Month	Actual Sorties Flown	Aircraft Ratio	Adjusted Aircraft	UTE Ratio	Adjusted Sorties Flown
Oct	464	1.00	464	1.00	464
Nov	398	1.00	398	1.00	398
Dec	364	1.00	364	1.00	364
Jan	406	1.00	406	1.00	406
Feb	386	1.00	386	1.00	386
Mar	435	1.00	435	1.00	435
Apr	509	1.00	509	1.00	509
May	405	1.00	405	1.00	405
Jun	370	1.00	370	1.00	370
Jul	544	1.00	544	1.00	544
Aug	294	1.00	294	1.00	294
Sep	393	1.00	393	1.00	393
Sum	4968		4968		4968
Mean	414		414		414
Aircraft	36		36		36
Annual UTE	11.50		11.50		11.50

Table 21. Adjustments to F-111 FY 1986 Actual Sorties Flown

Month	Actual Sorties Flown	Aircraft Ratio	Adjusted Aircraft	UTE Ratio	Adjusted Sorties Flown
Oct	1413	1.00	1413	0.93	1519
Nov	1355	1.00	1355	0.93	1457
Dec	1581	1.00	1581	0.93	1700
Jan	1391	1.00	1391	0.93	1495
Feb	1251	1.00	1251	0.93	1345
Mar	1484	1.00	1484	0.93	1595
Apr	1595	1.00	1595	0.93	1715
May	1501	1.00	1501	0.93	1614
Jun	1551	1.00	1551	0.93	1667
Jul	1520	1.00	1520	0.93	1634
Aug	1613	1.00	1613	0.93	1734
Sep	1106	1.00	1106	0.93	1189
Sum	17361		17358		18662
Mean	1447		1446		1555
Aircraft	72		72		72
Annual UTE	20.09		20.09		21.60

Table 22. Adjustments to F-15 FY 1983 Actual Sorties Flown

Month	Actual Sorties Flown	Aircraft Ratio	Adjusted Aircraft	UTE Ratio	Adjusted Sorties Flown
Oct	1594	1.00	1594	0.98	1632
Nov	1761	1.00	1761	0.98	1803
Dec	1541	1.00	1541	0.98	1578
Jan	1491	1.00	1491	0.98	1527
Feb	1322	1.00	1322	0.98	1354
Mar	1623	1.00	1623	0.98	1662
Apr	1569	1.00	1569	0.98	1606
May	1645	1.00	1645	0.98	1684
Jun	1586	1.00	1586	0.98	1624
Jul	1385	1.00	1385	0.98	1418
Aug	1713	1.00	1713	0.98	1754
Sep	998	1.00	998	0.98	1022
Sum	18228		18230		18662
Mean	1519		1519		1555
Aircraft	72		72		72
Annual UTE	21.10		21.10		21.60

Table 23. Adjustments to F-15 FY 1984 Actual Sorties Flown

Month	Actual Sorties Flown	Aircraft Ratio	Adjusted Aircraft	UTE Ratio	Adjusted Sorties Flown
Oct	1769	1.00	1769	1.03	1718
Nov	1560	1.00	1560	1.03	1515
Dec	1367	1.00	1367	1.03	1328
Jan	1475	1.00	1475	1.03	1433
Feb	1642	1.00	1642	1.03	1595
Mar	2318	1.00	2318	1.03	2251
Apr	1261	1.00	1261	1.03	1225
May	1610	1.00	1610	1.03	1564
Jun	1644	1.00	1644	1.03	1597
Jul	1733	1.00	1733	1.03	1683
Aug	1602	1.00	1602	1.03	1556
Sep	1235	1.00	1235	1.03	1199
Sum	19216		19215		18662
Mean	1601		1601		1555
Aircraft	72		72		72
Annual UTE	22.24		22.24		21.60

Table 24. Adjustments to F-15 FY 1985 Actual Sorties Flown

The patterns of the adjusted actual sorties flown for each wing exhibited neither increasing nor decreasing trend. In fact, the data exhibited a horizontal pattern, which indicated some stationarity around the mean. This phenomena was consistent with the practice of monthly flying higher or lower UTE rates than the headquarters assigned UTE rate for the wing. Seasonality was indicated in the patterns. The patterns were generally repeated every 12 months. The valleys in the patterns were generally attributed to attaining the annual sortie goal at the end of the fiscal year; while the peaks were generally indications of sortie surges.

Four time series forecasting techniques were then chosen based on the patterns depicted by the graphs. These techniques were considered best suited to handle the patterns. The four techniques were the moving average,

Figure 2. Graph of A-10 Adjusted Sorties

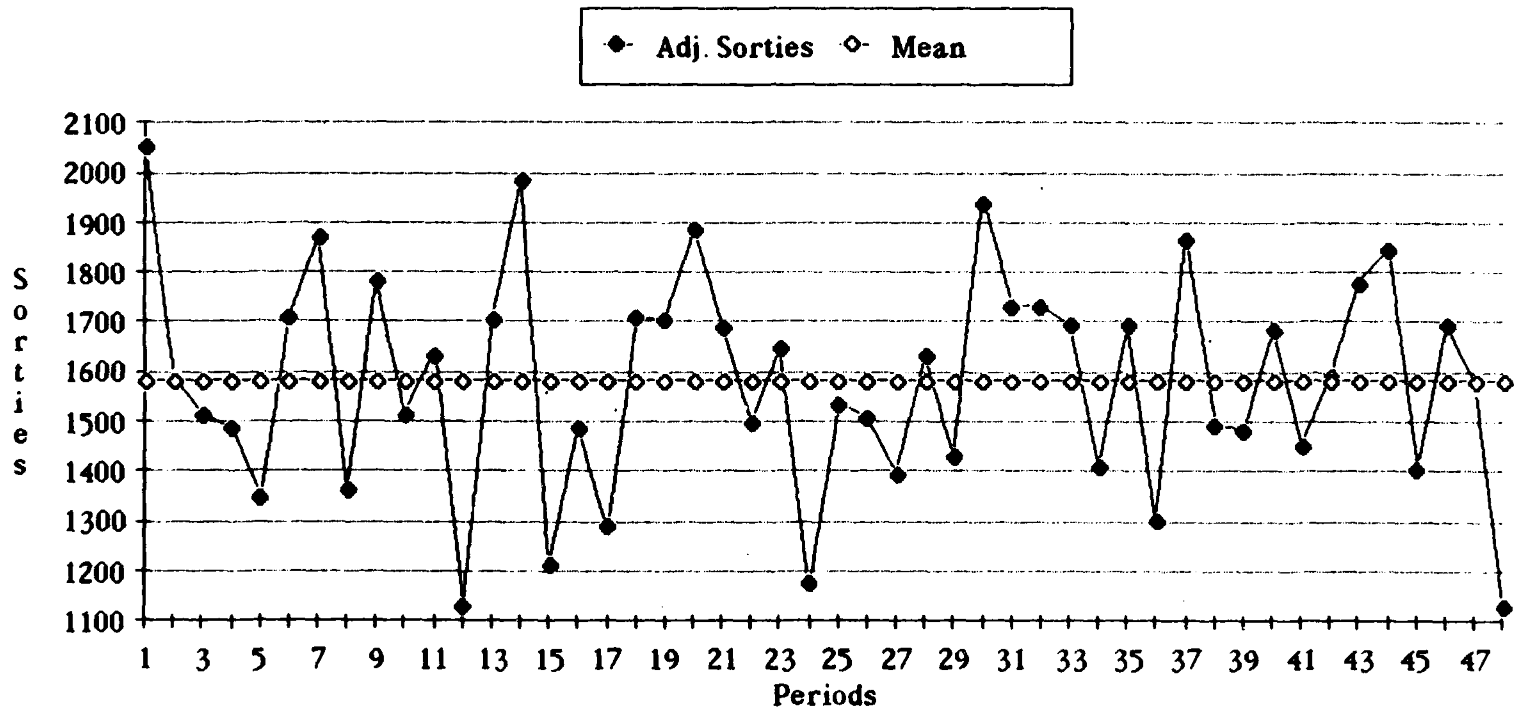


Figure 3. Graph of F-4 Adjusted Sorties

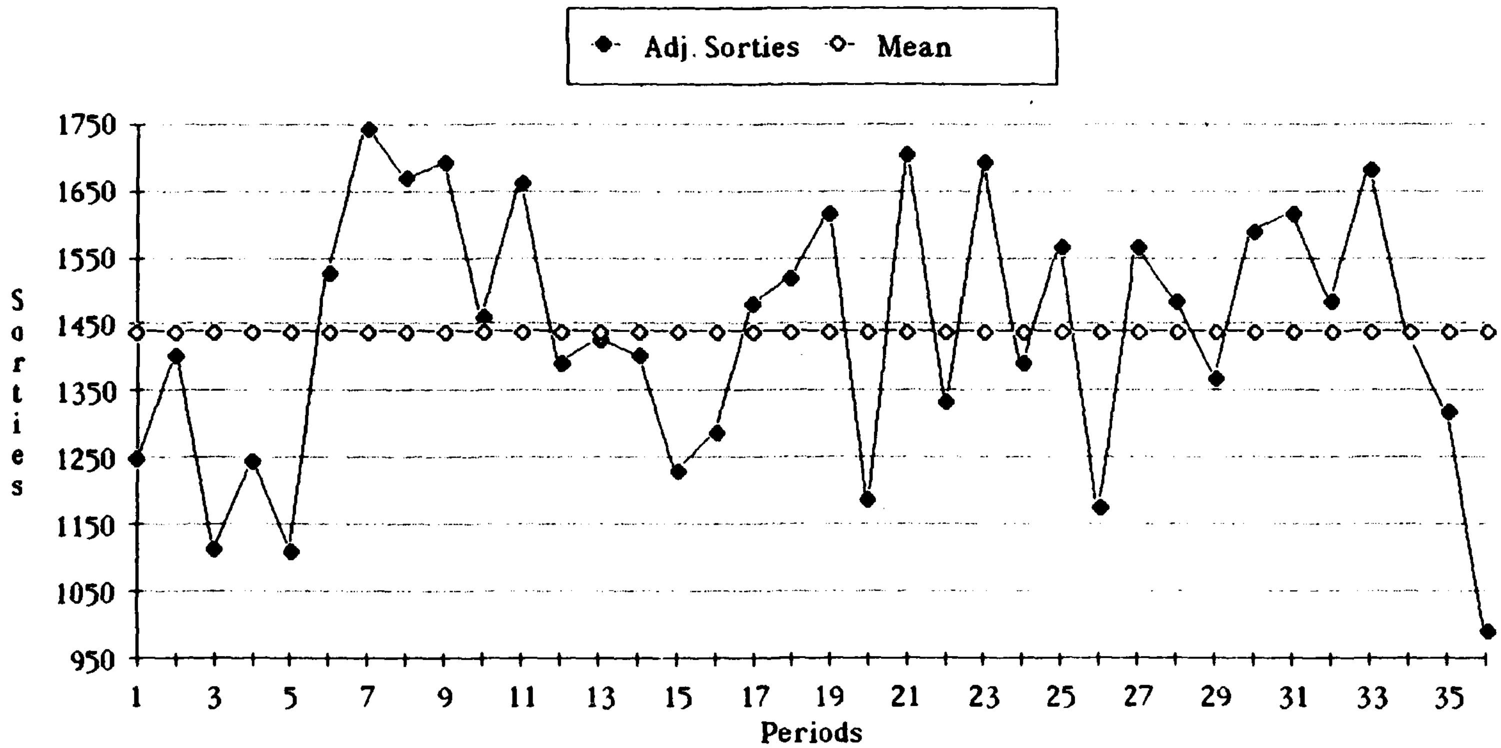


Figure 4. Graph of F-16 Adjusted Sorties

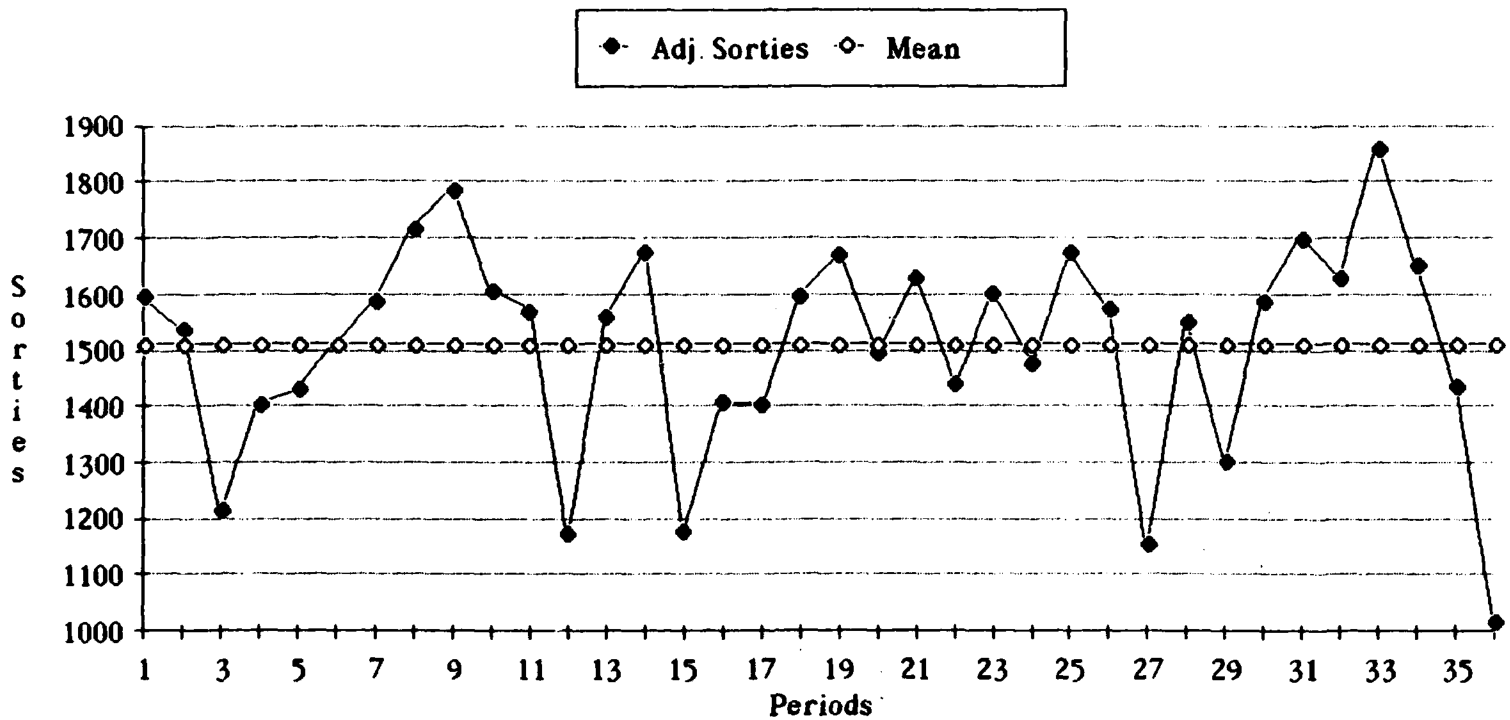


Figure 5. Graph of F-111 Adjusted Sorties

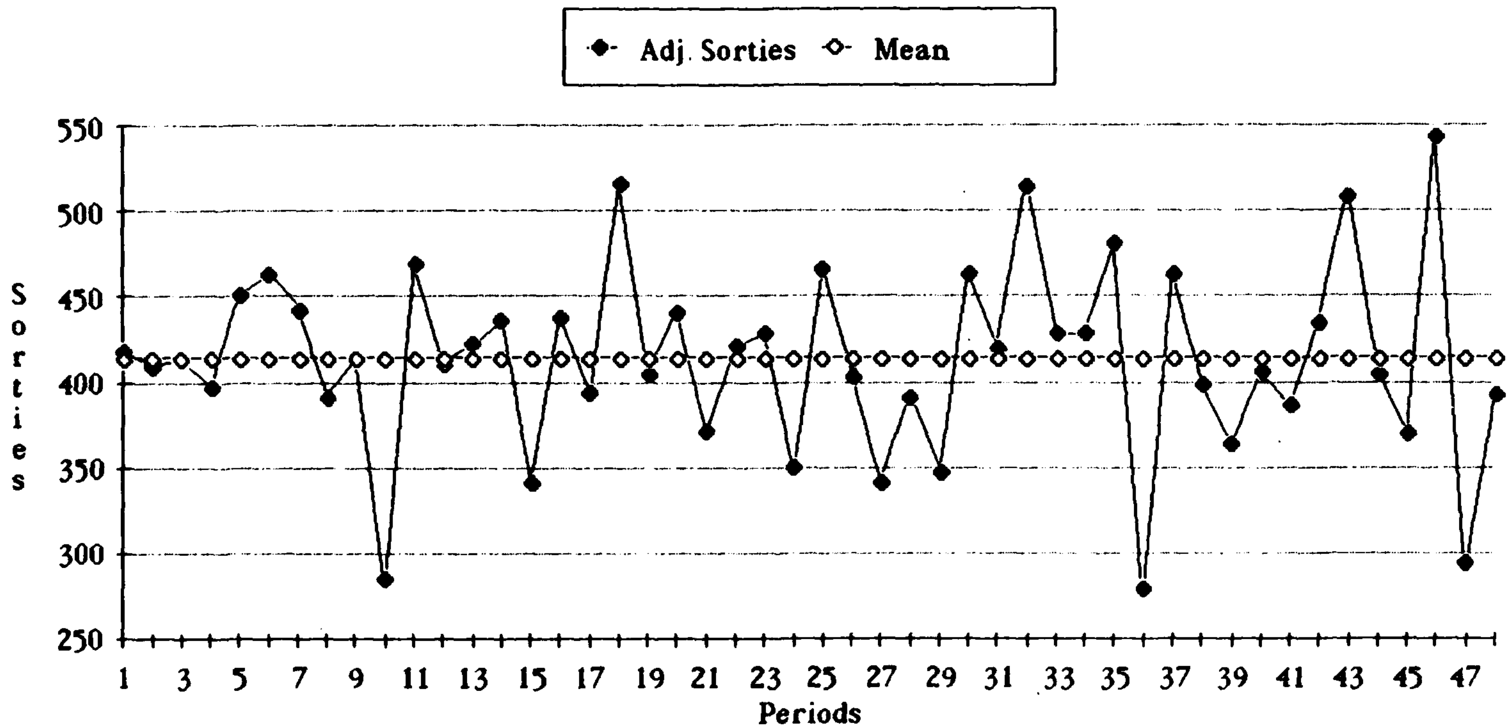
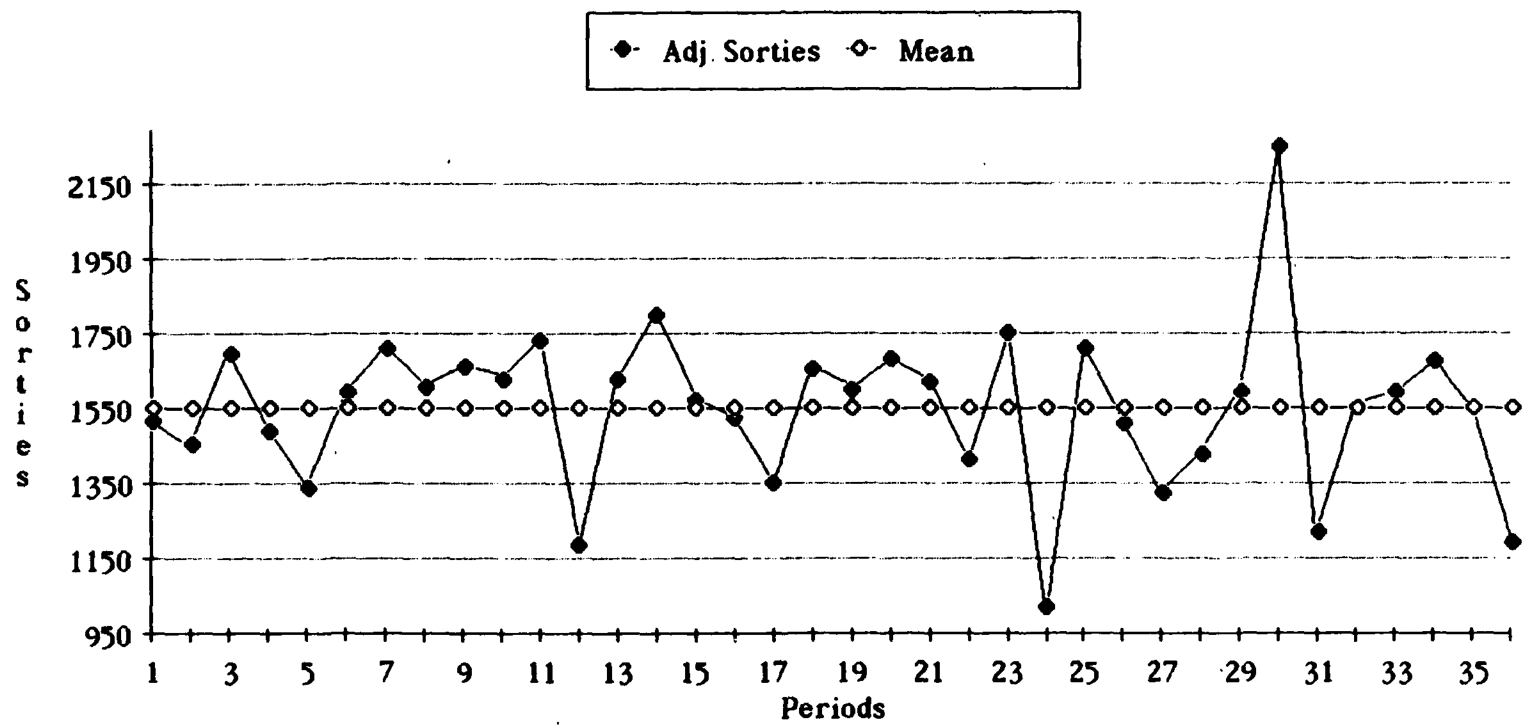


Figure 6. Graph of F-15 Adjusted Sorties



the modified moving average, the Winters' Linear and Seasonal Exponential Smoothing, and the Box-Jenkins.

The Moving Average Forecasting Technique. Two moving average techniques were used in this research. The first technique used the 12 preceding adjusted sortie data values to predict the next period. The technique is represented in the following way:

$$\hat{Y}_t = (Y_{t-1} + Y_{t-2} + Y_{t-3} + \ldots + Y_{t-12})/12;$$

where:

$\hat{Y}_t$ = the forecast value of Y for time t,

Y_t = the actual value of Y at time t.

This technique only averages the preceding data values and does not account for data seasonality. Therefore, a modified moving average technique was used to consider the effects of data seasonality on the forecast.

The modified moving average technique accounts for data seasonality by averaging the data value for each month by fiscal year. This technique is represented in the following way:

Month FY87 = (Mon FY86 + Mon FY85 + Mon FY84 + Mon FY83)/4

where:

Mon. = Number of sorties flown in October, November, December, January, February, March, April, May, June, July August and September.

The Winters' Linear and Seasonal Exponential Smoothing Forecasting Technique. Exponential smoothing techniques used a weighted sum of past observations to predict the future. "Since the exponentially smoothed forecast is constant for all future values, any changes in trend and/or

seasonality are not taken into account" (11:631). To achieve an exponential smoothing technique with seasonal data, the Winters' Linear and Seasonal Exponential Smoothing method was used. "This method is based on three equations, each of which smooths a parameter associated with one of the three components of the pattern" (20:73). The three equations are:

$$I_t = \beta(Y_t/S_t) + (1-\beta)I_{t-L}$$
$$S_t = \alpha(Y_t/I_{t-L}) + (1-\alpha)(S_{t-1}+T_{t-1})$$
$$T_t = \gamma(S_t-S_{t-1}) + (1-\gamma)T_{t-1}$$

where:

I_t = seasonal index,
β = constant to smooth seasonality,
Y_t = the actual value of Y at time t,
S_t = smoothed value for seasonality,
α = constant to smooth randomness,
T_t = smoothed value for trend,
γ = constant to smooth trend,
L = the length of seasonality [10:98].

The equation for I_t calculates a seasonal index which fluctuates around one. This is used in the S_t equation to adjust the observed data, Y_t, for seasonality. The T_t equation is used to smooth the trend in the observed data.

The forecast based on Winters' method is computed as:

$$F_{t+m} = (S_t+mT_t)I_{t-L+m}$$

where:

m = the number of periods to be forecasted [10:98].

For further details on the development and explanation of this forecasting technique refer to Winters (1960).

The Box-Jenkins Forecasting Technique. Like exponential smoothing, the Box-Jenkins forecasting technique is based on a weighted sum of previous observations (8:94). This technique is usually divided into three main stages (Figure 7). The stages are:

1. Selecting a suitable class of models for fitting to the observed time series.
2. Fitting an appropriate model from this class to the observed time series.
3. Using the fitted model to make forecasts of future values of the time series [13:77].

The first stage involves the selection of an appropriate model for the observed time series. In order to achieve this selection, the observed time series must exhibit stationarity. Stationarity in the data is achieved when the mean and variance of the data are constant and the autocorrelation of the data rapidly decrease to zero (19:14). The autocorrelation "is a correlation between observations of the same series at different time periods" (19:14). If the data are not stationary, then the first difference of the data is calculated and the autocorrelations of the differenced data is examined for stationarity. The first difference is calculated by subtracting the successive observed values from each other. "For all practical purposes, stationarity will exist in the original, first or second differenced series" (10:252). Once stationarity has been achieved, then the data is used in an autoregressive-moving average (ARMA) model. The following is the equation for the general class of ARMA models:

$$Y_t = \phi_1 Y_{t-1} + \phi_2 Y_{t-2} + \ldots + \phi_p Y_{t-p} + e_t - \theta_1 e_{t-1} - \theta_2 e_{t-2} - \ldots - \theta_q e_{t-q}$$

where:

Y_t - the forecasted period

ϕ - autoregressive parameter.

p - autoregressive order.

θ - moving average parameter.

q - moving average order.

e - the error term. [10:245]

The next stage consists of selecting the appropriate ARMA model from the observed time series. The first task in this stage is to identify the autocorrelation function (ACF) and the partial autocorrelation function (PACF) for the observed data. PACFs are similar to the ACFs. "The PACF are computed for each time lag after removing the effect of all other time lags on the given time lag and on the original series" (10:247). The ACF and PACF are then compared to theoretical ACFs and PACFs. The theoretical ACFs and PACFs indicate the specific type of ARMA model. If the ACF and PACF of the observed data match theoretical ACF and PACF, then the associated ARMA model is used for the forecast. "This stage is probably the most difficult stage in the Box-Jenkins approach and requires a skill that only comes with experience" (13:78). The next stage of the Box-Jenkins method will check for and identify incorrect ARMA models.

The final stage consists of fitting the observed data in the chosen ARMA model. Diagnostic checks are applied to the ARMA model to determine how well the model performs. If the diagnostic checks indicate that the model is inadequate in predicting the future, then the process of identifying the ARMA model is reaccomplished. These procedures are repeated until an adequate ARMA model is selected.

Since the historical sortie data exhibited seasonality, the ARMA models can be adjusted with a seasonal coefficient. The seasonal coefficient can

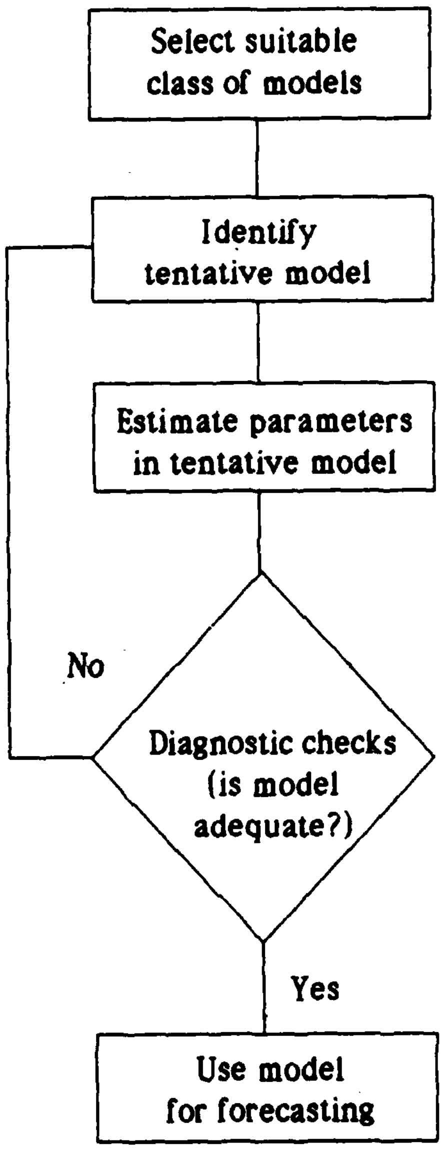


Figure 7. Stages in the Box-Jenkins Approach (13:78)

either be in the autogressive or moving average equation. The following two equations represent the seasonal coefficient:

$$Y_t = a + \phi_1 Y_{t-1} + (\phi_s Y_{t-L} + \phi_1 \phi_s Y_{t-L-1}) + e_t - \theta_1 e_{t-1}$$

$$Y_t = a + \phi_1 Y_{t-1} + e_t - \theta_1 e_{t-1} - (\theta_s e_{t-L} + \theta_1 \theta_s e_{t-L-1})$$

where:

ϕ_s = the autogressive seasonal coefficient.

θ_s = the moving average seasonal coefficient.

For further details on the development and explanation of this forecasting technique refer to Box and Jenkins (1976).

Diagnostic Check of Forecast Models

"By applying various diagnostic checks, we can determine whether or not the model adequately represents the data" (19:62). The diagnostic check provides a statistical analysis for determining how well the forecast model fits the historical data. Two types of diagnostic checks were used for the Winters' Linear and Seasonal Exponential Smoothing and Box-Jenkins forecasting techniques. They were the Durbin-Watson d statistic and the Ljung-Box Q statistic

The Durbin-Watson Statistic.

"The Durbin-Watson d statistic is calculated as the ratio of the sum of squares of the first differences of the errors, divided by the sum of squares of the errors" (6:6-5). The statistic is used to test for the presence of first-order autocorrelation. If the autocorrelation is high, then the model is considered inadequate. The value of the statistic will

always be between zero and four. If the errors are not correlated, then the statistic is equal to two and the model is considered a perfect fit. When the autocorrelation of the errors is positive, then the statistic is less than two. On the other hand, when the autocorrelation is negative, then the statistic is greater than two. In either case, when the statistic approaches zero or four, the autocorrelations are considered very strong. For further details on the development and explanation of this diagnostic technique refer to Durbin and Watson (1950).

The Ljung-Box Statistic. The Ljung-Box Q statistic, sometimes called the Portmanteau test, also examines the error autocorrelations. However, this statistic considers a group of autocorrelations, instead of individual autocorrelations as in the Durbin-Watson d statistic. "The statistic is distributed approximately as a χ^2 (chi-square) distribution with K degrees of freedom" (19:108). The degrees of freedom are the number of data points available after differencing the observed series and the number of autocorrelations used in the summation. When the autocorrelations are random, then the statistic will be less than the table value for χ^2 and the model is considered adequate. However, when the autocorrelations exhibit some pattern, then the statistic will be greater than the table value for χ^2. For further details on the development and explanation of this diagnostic technique refer to Ljung and Box (1978).

Forecasting Accuracy

The measure of accuracy for a forecast is based on a summary of the error terms in the forecasted time period. The errors are the difference between the actual values and the predicted values. "Error terms occur because even when the exact pattern of the underlying data has been identified some deviation will still exist between the forecast values and the values actually observed" (20:22). The accuracy of a forecasting technique increases as the sum of error terms approaches zero.

One method for determining the summary of error terms would be to sum the errors and calculate its mean. However, there are some inherent problems with this method. Negative errors would reduce positive errors and, with large compensating errors, the mean of the error terms could be close to zero. For example, if the error terms for five periods were 234, -220, -252, 180 and 200, then the mean of the error terms would be 28.4. While the individual error terms indicate a large difference between the actual observed value and the forecasted value, the mean of the error terms does not reflect this difference.

To overcome this problem, most forecasters use the mean absolute deviation (MAD) as the measure of accuracy for their forecasts. The MAD is obtained by taking the absolute value of the error terms and then calculating its mean. The MAD for the error term values in the above example would be 217.2. The MAD therefore provides a better indication of the magnitude of individual error terms.

Another method is called the mean squared error (MSE). The MSE is obtained by squaring the error terms and then calculating its mean. By squaring the error terms negative numbers are once again avoided. The MSE

gives greater importance to large error terms. The MSE for the error term values in the above example would be 47,812.

The MSE is considered a descriptive accuracy measure (4:448). It is used in this research to measure the accuracy of the different forecasting techniques. First, each wing's forecasted sortie schedule will be compared to the actual sorties flown; then the moving average, the modified moving average, the Winters' Linear and Seasonal Exponential Smoothing and the Box-Jenkins forecasting techniques will be compared to the actual sorties flown.

III. Findings and Analysis

In this chapter of the research the forecasts of the four time series techniques are reported. The time series techniques used four years of historical data to predict the fifth year. Two diagnostic checks were performed on the Winters' Linear and Seasonal Exponential Smoothing and the Box-Jenkins techniques to ensure the models were statistically adequate. The forecasted sortie values from the time series techniques and the wing's forecasted monthly sortie schedule, developed during the operational planning cycle, were then compared to the actual sorties flown at each wing (the data from the fifth year) to determine which forecasting technique produced the best result. The mean squared error (MSE) was used as the measure of accuracy to determine the best forecast. The forecast with the lowest MSE value is considered the most accurate.

The Winters' Linear and Seasonal Exponential Smoothing and Box-Jenkins forecasting techniques were calculated using a software package called Forecast Master. Forecast Master was chosen for two reasons. First, the software can be run on a Zenith 248 personal computer. This computer is used throughout the Air Force and is available at all maintenance units. Second, each operational wing has the capability of using the forecasting techniques in this research by obtaining the forecasting software through Air Force channels.

Findings of the Forecasting Techniques for the A-10 Data

The accuracy of the wing's forecasted monthly sortie schedule as currently calculated and developed during the operations planning cycle, is recorded in Table 25. Tables 26 and 27 record the forecasted sortie values and the accuracy of the moving average and the modified moving average techniques.

For the Winters' Linear and Seasonal Exponential Smoothing technique, the seasonal smoothing constant, β, was .329, the trend smoothing constant, α, was .105, and the randomness smoothing constant, γ, was .054. The Durbin-Watson and the Ljung-Box statistics were used to test the adequacy of the model. The Durbin-Watson statistic was 2.5 and the Ljung-Box statistic was 14.50 with 15 degrees of freedom. The χ^2 table value for 15 degrees of freedom at the 95% confidence level was 25.00. Both statistics indicated that the models were adequate. The MSE for the Winters' forecast, as well as the forecasted sortie values, is recorded in Table 28.

For the Box-Jenkins forecasting technique the Durbin-Watson statistic was 1.9 and the Ljung-Box statistic was 9.48 with 14 degrees of freedom. The χ^2 table value for 14 degrees of freedom at the 95% confidence level was 23.68. Again, both statistics indicated that the models were adequate. The Box-Jenkins forecasted sortie values and the MSE are recorded in Table 29.

Month	Actual Sorties Flown	Forecast	Error	Absolute Error	Squared Error
Oct	1902	2104	-202	202	40804
Nov	1317	1525	-208	208	43264
Dec	1476	1466	10	10	100
Jan	1578	1686	-108	108	11664
Feb	1481	1678	-197	197	38809
Mar	1788	1848	-60	60	3600
Apr	1686	1854	-168	168	28224
May	1582	1662	-80	80	6400
Jun	1718	1906	-188	188	35344
Jul	1721	1851	-130	130	16900
Aug	1633	1697	-64	64	4096
Sep	1218	1438	-220	220	48400
Sum			-1615	1635	277605
Mean			-134.58	136.25	23133.75

Table 25. Accuracy of the Wing Forecast for the A-10.

Month	Actual Sorties Flown	Forecast	Error	Absolute Error	Squared Error
Oct	1902	1584	318	318	101124
Nov	1317	1561	-244	244	59536
Dec	1476	1566	-90	90	8100
Jan	1578	1573	5	5	25
Feb	1481	1563	-82	82	6724
Mar	1788	1573	215	215	46225
Apr	1686	1571	115	115	13225
May	1582	1554	28	28	784
Jun	1718	1529	189	189	35721
Jul	1721	1540	181	181	32761
Aug	1633	1527	106	106	11236
Sep	1218	1523	-305	305	93025
Sum			436	1878	408486
Mean			36.33	156.50	34040.50

Table 26. Accuracy of the Moving Average Forecast for the A-10.

Month	Actual Sorties Flown	Forecast	Error	Absolute Error	Squared Error
Oct	1902	1790	112	112	12544
Nov	1317	1644	-327	327	106929
Dec	1476	1402	74	74	5476
Jan	1578	1574	4	4	16
Feb	1481	1381	100	100	10000
Mar	1788	1738	50	50	2500
Apr	1686	1773	-87	87	7569
May	1582	1707	-125	125	15625
Jun	1718	1645	73	73	5329
Jul	1721	1529	192	192	36864
Aug	1633	1638	-5	5	25
Sep	1218	1186	32	32	1024
Sum			93	1181	203901
Mean			7.75	98.42	16991.75

Table 27. Accuracy of the Mod. Moving Average Forecast for the A-10.

Month	Actual Sorties Flown	Forecast	Error	Absolute Error	Squared Error
Oct	1902	1774	128	128	16384
Nov	1317	1621	-304	304	92416
Dec	1476	1429	47	47	2209
Jan	1578	1603	-25	25	625
Feb	1481	1410	71	71	5041
Mar	1788	1727	61	61	3721
Apr	1686	1769	-83	83	6889
May	1582	1737	-155	155	24025
Jun	1718	1613	105	105	11025
Jul	1721	1559	162	162	26244
Aug	1633	1641	-8	8	64
Sep	1218	1215	3	3	9
Sum			2	1152	188652
Mean			0.17	96.00	15721.00

Table 28. Accuracy of the Winters Forecast for the A-10.

Month	Actual Sorties Flown	Forecast	Error	Absolute Error	Squared Error
Oct	1902	1827	75	75	5625
Nov	1317	1491	-174	174	30276
Dec	1476	1519	-43	43	1849
Jan	1578	1704	-126	126	15876
Feb	1481	1501	-20	20	400
Mar	1788	1624	164	164	26896
Apr	1686	1695	-9	9	81
May	1582	1726	-144	144	20736
Jun	1718	1514	204	204	41616
Jul	1721	1618	103	103	10609
Aug	1633	1592	41	41	1681
Sep	1218	1334	-116	116	13456
Sum			-45	1219	169101
Mean			-3.75	101.58	14091.75

Table 29. Accuracy of the Box-Jenkins Forecast for the A-10.

Analysis of the Forecasting Techniques for the A-10 Data

The three time series forecasting techniques all provided more accurate forecasts than the forecasting methodology used by the wing. The Box-Jenkins, the Winters' Linear and Seasonal Exponential Smoothing and the modified moving average techniques yielded a mean squared error (MSE) value lower than the wing's MSE value of 23,133.75. The Box-Jenkins forecasting technique had the lowest MSE with a value of 14,091.75, which was a 39% reduction from the wing's MSE value.

The highest mean squared error value was recorded for the months of November and July for the three time series techniques. Since data variability, the variation from the mean, affects the accuracy of the

forecasting techniques it is useful to examine the historical data closely. The historical data for November indicated that, for fiscal year 1983, the wing flew less than 1% above the mean, for 1984 -- 33% above the mean, for 1985 -- 4.89% below the mean, and for 1986 -- 5.56% below the mean. The 1984 data value, which was more than one standard deviation above the mean, had an influence on the forecasting techniques (see period 14 on Figure 2). This caused each time series technique to have a forecasted value much higher than the number of sorties flown for the forecasted year. On the other hand, the historical data for the month of July were all within one standard deviation of the mean. However, the number of sorties flown was greater than what was flown in the past. Therefore, the forecasted sortie values were much lower than the actual.

The 12-month moving average technique had a MSE value greater than the wing's MSE -- 34,040.50. This technique did not adjust for seasonality in the data; therefore, the forecasted data values were relatively the same for all months in the time period.

Findings of the Forecasting Techniques for the F-4 Data

The accuracy of the wing's forecasted monthly sortie schedule and the sortie values are recorded in Table 30. Tables 31 and 32 record the forecasted sortie values and the accuracy of the moving average and the modified moving average techniques.

For the Winters' Linear and Seasonal Exponential Smoothing technique, the seasonal smoothing constant, β, was .213, the trend smoothing constant, α, was .010, and the randomness smoothing constant, γ, was .100. The

Month	Actual Sorties Flown	Forecast	Error	Absolute Error	Squared Error
Oct	1729	1643	86	86	7396
Nov	993	1420	-427	427	182329
Dec	1561	1642	-81	81	6561
Jan	1422	1599	-177	177	31329
Feb	1440	1474	-34	34	1156
Mar	1450	1658	-208	208	43264
Apr	1798	1862	-64	64	4096
May	1400	1518	-118	118	13924
Jun	1696	1553	143	143	20449
Jul	1507	1496	11	11	121
Aug	1367	1480	-113	113	12769
Sep	985	1142	-157	157	24649
Sum			-1139	1619	348043
Mean			-94.92	134.92	29003.58

Table 30. Accuracy of the Wing Forecast for the F-4.

Month	Actual Sorties Flown	Forecast	Error	Absolute Error	Squared Error
Oct	1729	1440	289	289	83521
Nov	993	1429	-436	436	190096
Dec	1561	1451	110	110	12100
Jan	1422	1441	-19	19	361
Feb	1440	1437	3	3	9
Mar	1450	1443	7	7	49
Apr	1798	1431	367	367	134689
May	1400	1415	-15	15	225
Jun	1696	1409	287	287	82369
Jul	1507	1387	120	120	14400
Aug	1367	1383	-16	16	256
Sep	985	1388	-403	403	162409
Sum			294	2072	680484
Mean			24.50	172.67	56707.00

Table 31. Accuracy of the Moving Average Forecast for the F-4.

Month	Actual Sorties Flown	Forecast	Error	Absolute Error	Squared Error
Oct	1729	1415	314	314	98596
Nov	993	1328	-335	335	112225
Dec	1561	1304	257	257	66049
Jan	1422	1339	83	83	6889
Feb	1440	1321	119	119	14161
Mar	1450	1546	-96	96	9216
Apr	1798	1660	138	138	19044
May	1400	1447	-47	47	2209
Jun	1696	1693	3	3	9
Jul	1507	1410	97	97	9409
Aug	1367	1557	-190	190	36100
Sep	985	1259	-274	274	75076
Sum			69	1953	448983
Mean			5.75	162.75	37415.25

Table 32. Accuracy of the Mod. Moving Average Forecast for the F-4.

Month	Actual Sorties Flown	Forecast	Error	Absolute Error	Squared Error
Oct	1729	1357	372	372	138384
Nov	993	1286	-293	293	85849
Dec	1561	1277	284	284	80656
Jan	1422	1294	128	128	16384
Feb	1440	1275	165	165	27225
Mar	1450	1429	21	21	441
Apr	1798	1505	293	293	85849
May	1400	1359	41	41	1681
Jun	1696	1539	157	157	24649
Jul	1507	1346	161	161	25921
Aug	1367	1447	-80	80	6400
Sep	985	1239	-254	254	64516
Sum			995	2249	557955
Mean			82.92	187.42	46496.25

Table 33. Accuracy of the Winters Forecast for the F-4.

Month	Actual Sorties Flown	Forecast	Error	Absolute Error	Squared Error
Oct	1729	1508	221	221	48841
Nov	993	1359	-366	366	133956
Dec	1561	1461	100	100	10000
Jan	1422	1442	-20	20	400
Feb	1440	1418	22	22	484
Mar	1450	1490	-40	40	1600
Apr	1798	1507	291	291	84681
May	1400	1441	-41	41	1681
Jun	1696	1530	166	166	27556
Jul	1507	1432	75	75	5625
Aug	1367	1421	-54	54	2916
Sep	985	1304	-319	319	101761
Sum			35	1715	419501
Mean			2.92	142.92	34958.42

Table 34. Accuracy of the Box-Jenkins Forecast for the F-4.

Durbin-Watson statistic was 1.6 and the Ljung-Box statistic was 18.50 with 15 degrees of freedom. The χ^2 table value for 15 degrees of freedom at the 95% confidence level was 25.00. Both statistics indicated that the models were adequate. The Winters' forecasted sortie values and the MSE are recorded in Table 33.

For the Box-Jenkins forecasting technique the Durbin-Watson statistic was 1.6 and the Ljung-Box statistic was 14.26 with 16 degrees of freedom. The χ^2 table value for 16 degrees of freedom at the 95% confidence level was 26.30. Again, both statistics indicated that the models were adequate. The Box-Jenkins forecasted sortie values and the MSE are recorded in Table 34.

Analysis of the Forecasting Techniques for the F-4 Data

For the F-4 historical data, only three of the four years were used with the time series forecasting techniques. The data for fiscal year 1985 was not used because during that period the wing was transitioning from 96 aircraft in fiscal year 1984 to 72 aircraft in fiscal year 1986. Therefore, only fiscal years 1983, 1984 and 1986 were used with the time series techniques.

All four time series forecasting techniques produced MSE values greater than the wing's MSE value of 29,003.58. The results of the time series techniques were most likely caused by the affects of a change in the mission of the wing. A noticeable change occurred after fiscal year 1985 when the wing reduced the number of possessed aircraft. As Table 2 and Figure 3 indicated, there were similar patterns in the number of sorties flown each month for fiscal years 1983 and 1984 data. This differed from the pattern in the number of sorties for fiscal years 1986 and 1987. Therefore, the fiscal years 1983 and 1984 data were not representative of the current mission operations at the wing.

However, of the time series forecasting techniques, the Box-Jenkins technique yielded the lowest MSE value with 34,958.42. Several months had high squared error values for the time series forecasting techniques. October, November, December, April and September had the highest. The historical data for October were all within one standard deviation from the mean. However, the high squared error value was due to the fact that the number of sorties flown for the forecasted year was greater than the adjusted historical sortie data. For the month of November, the number of sorties flown had dropped dramatically from past historical sortie data

values. This accounts for the high squared error values in each forecasting technique. The high squared error value for December was a result of the historical data for fiscal years 1983 and 1984. For both of these periods the values were greater than one standard deviation below the mean. These two time periods influenced the time series techniques to forecast a low sortie value. The high squared error value for April was for the same reason as for the month of October. And the high squared error value for September was caused by a similar situation as for November.

Findings of the Forecasting Techniques for the F-16 Data

The accuracy of the wing's forecasted monthly sortie schedule and the sortie values are recorded in Table 35. Tables 36 and 37 record the forecasted sortie values and the accuracy of the moving average and the modified moving average techniques.

For the Winters' Linear and Seasonal Exponential Smoothing technique, the seasonal smoothing constant, β, was .387, the trend smoothing constant, α, was .140, and the randomness smoothing constant, γ, was .088. The Durbin-Watson statistic was 1.2 and the Ljung-Box statistic was 24.58 with 15 degrees of freedom. The χ^2 table value for 15 degrees of freedom at the 95% confidence level was 25.00. Both statistics indicated that the models were adequate. The Winters' forecasted sortie values and the MSE are recorded in Table 38.

For the Box-Jenkins forecasting technique the Durbin-Watson statistic was 1.9 and the Ljung-Box statistic was 17.50 with 16 degrees of freedom. The χ^2 table value for 16 degrees of freedom at the 95% confidence level

Month	Actual Sorties Flown	Forecast	Error	Absolute Error	Squared Error
Oct	1816	2050	-234	234	54756
Nov	1549	1726	-177	177	31329
Dec	1421	1615	-194	194	37636
Jan	1396	1773	-377	377	142129
Feb	1515	1754	-239	239	57121
Mar	1599	1875	-276	276	76176
Apr	1835	1923	-88	88	7744
May	1376	1642	-266	266	70756
Jun	1740	1801	-61	61	3721
Jul	1935	2258	-323	323	104329
Aug	1742	1839	-97	97	9409
Sep	1150	1288	-138	138	19044
Sum			-2470	2470	614150
Mean			-205.83	205.83	51179.17

Table 35. Accuracy of the Wing Forecast for the F-16.

Month	Actual Sorties Flown	Forecast	Error	Absolute Error	Squared Error
Oct	1816	1512	304	304	92416
Nov	1549	1498	51	51	2601
Dec	1421	1492	-71	71	5041
Jan	1396	1520	-124	124	15376
Feb	1515	1518	-3	3	9
Mar	1599	1536	63	63	3969
Apr	1835	1531	304	304	92416
May	1376	1517	-141	141	19881
Jun	1740	1508	232	232	53824
Jul	1935	1478	457	457	208849
Aug	1742	1464	278	278	77284
Sep	1150	1466	-316	316	99856
Sum			1034	2344	671522
Mean			86.17	195.33	55960.17

Table 36. Accuracy of the Moving Average Forecast for the F-16.

Month	Actual Sorties Flown	Forecast	Error	Absolute Error	Squared Error
Oct	1816	1611	205	205	42025
Nov	1549	1597	-48	48	2304
Dec	1421	1182	239	239	57121
Jan	1396	1454	-58	58	3364
Feb	1515	1379	136	136	18496
Mar	1599	1566	33	33	1089
Apr	1835	1654	181	181	32761
May	1376	1615	-239	239	57121
Jun	1740	1759	-19	19	361
Jul	1935	1566	369	369	136161
Aug	1742	1536	206	206	42436
Sep	1150	1224	-74	74	5476
Sum			931	1807	398715
Mean			77.58	150.58	33226.25

Table 37. Accuracy of the Mod. Moving Average Forecast for the F-16.

Month	Actual Sorties Flown	Forecast	Error	Absolute Error	Squared Error
Oct	1816	1592	224	224	50176
Nov	1549	1567	-18	18	324
Dec	1421	1176	245	245	60025
Jan	1396	1442	-46	46	2116
Feb	1515	1345	170	170	28900
Mar	1599	1533	66	66	4356
Apr	1835	1613	222	222	49284
May	1376	1564	-188	188	35344
Jun	1740	1709	31	31	961
Jul	1935	1529	406	406	164836
Aug	1742	1483	259	259	67081
Sep	1150	1191	-41	41	1681
Sum			1330	1916	465084
Mean			110.83	159.67	38757.00

Table 38. Accuracy of the Winters Forecast for the F-16.

Month	Actual Sorties Flown	Forecast	Error	Absolute Error	Squared Error
Oct	1816	1560	256	256	65536
Nov	1549	1647	-98	98	9604
Dec	1421	1258	163	163	26569
Jan	1396	1521	-125	125	15625
Feb	1515	1339	176	176	30976
Mar	1599	1581	18	18	324
Apr	1835	1676	159	159	25281
May	1376	1604	-228	228	51984
Jun	1740	1795	-55	55	3025
Jul	1935	1607	328	328	107584
Aug	1742	1472	270	270	72900
Sep	1150	1135	15	15	225
Sum			879	1891	409633
Mean			73.25	157.58	34136.08

Table 39. Accuracy of the Box-Jenkins Forecast for the F-16.

was 26.30. Again, both statistics indicated that the models were adequate. The Box-Jenkins forecasted sortie values and the MSE are recorded in Table 39.

Analysis of the Forecasting Techniques for the F-16 Data

The F-16 historical data indicated that during fiscal year 1983 the wing was building up the number of F-16 aircraft in its fighter squadrons. The wing averaged 56 F-16 aircraft for that year. The next fiscal year indicated 95 aircraft. Therefore, only fiscal years 1984, 1985, and 1986 historical data were used with the time series forecasting techniques.

Three of the four time series forecasting techniques yielded lower MSE values than the wing's MSE value of 51,179.17. The modified moving average technique had the lowest MSE value with 33,226.25. This was a 35% reduction of the MSE.

High squared error values were calculated for five months -- October, December, May, July and August. For October, the high squared error value was due to the fact that the number of sorties flown for the forecasted year was greater than the adjusted historical sortie data. All historical sortie values were within one standard deviation for that month. The historical sortie values for December were all greater than one standard deviation below the mean. This cause the time series techniques to forecast a low sortie value. The May historical sortie data indicated that only one time period was greater than one standard deviation above the mean. This time period influenced the forecasts of the time series techniques which resulted in a higher sortie forecast for the month. For both July and August, the historical sortie values were all within one standard deviation of the mean. However, the high squared error values were caused by higher than normal sortie rates for the two months. These were a dramatic increase from the adjusted actual sorties flown for the same months in the previous fiscal years.

Findings of the Forecasting Techniques for the F-111 Data

The accuracy of the wing's forecasted monthly sortie schedule and the sortie values are recorded in Table 40. Tables 41 and 42 record the

Month	Actual Sorties Flown	Forecast	Error	Absolute Error	Squared Error
Oct	474	540	-66	66	4356
Nov	399	467	-68	68	4624
Dec	346	464	-118	118	13924
Jan	428	544	-116	116	13456
Feb	393	443	-50	50	2500
Mar	416	453	-37	37	1369
Apr	465	530	-65	65	4225
May	441	493	-52	52	2704
Jun	463	562	-99	99	9801
Jul	450	477	-27	27	729
Aug	470	492	-22	22	484
Sep	360	463	-103	103	10609
Sum			-823	823	68781
Mean			-68.58	68.58	5731.75

Table 40. Accuracy of the Wing Forecast for the F-111.

Month	Actual Sorties Flown	Forecast	Error	Absolute Error	Squared Error
Oct	474	414	60	60	3600
Nov	399	410	-11	11	121
Dec	346	411	-65	65	4225
Jan	428	415	13	13	169
Feb	393	415	-22	22	484
Mar	416	418	-2	2	4
Apr	465	416	49	49	2401
May	441	409	32	32	1024
Jun	463	409	54	54	2916
Jul	450	412	38	38	1444
Aug	470	401	69	69	4761
Sep	360	410	-50	50	2500
Sum			165	465	23649
Mean			13.75	38.75	1970.75

Table 41. Accuracy of the Moving Average Forecast for the F-111.

Month	Actual Sorties Flown	Forecast	Error	Absolute Error	Squared Error
Oct	474	443	31	31	961
Nov	399	412	-13	13	169
Dec	346	365	-19	19	361
Jan	428	408	20	20	400
Feb	393	395	-2	2	4
Mar	416	470	-54	54	2916
Apr	465	445	20	20	400
May	441	438	3	3	9
Jun	463	396	67	67	4489
Jul	450	420	30	30	900
Aug	470	419	51	51	2601
Sep	360	358	2	2	4
Sum			136	312	13214
Mean			11.33	26.00	1101.17

Table 42. Accuracy of the Mod. Moving Average Forecast for the F-111.

Month	Actual Sorties Flown	Forecast	Error	Absolute Error	Squared Error
Oct	474	436	38	38	1444
Nov	399	409	-10	10	100
Dec	346	371	-25	25	625
Jan	428	406	22	22	484
Feb	393	395	-2	2	4
Mar	416	455	-39	39	1521
Apr	465	438	27	27	729
May	441	431	10	10	100
Jun	463	397	66	66	4356
Jul	450	422	28	28	784
Aug	470	411	59	59	3481
Sep	360	367	-7	7	49
Sum			167	333	13677
Mean			13.92	27.75	1139.75

Table 43. Accuracy of the Winters Forecast for the F-111.

Month	Actual Sorties Flown	Forecast	Error	Absolute Error	Squared Error
Oct	474	438	36	36	1296
Nov	399	409	-10	10	100
Dec	346	394	-48	48	2304
Jan	428	411	17	17	289
Feb	393	402	-9	9	81
Mar	416	424	-8	8	64
Apr	465	442	23	23	529
May	441	418	23	23	529
Jun	463	402	61	61	3721
Jul	450	453	-3	3	9
Aug	470	383	87	87	7569
Sep	360	399	-39	39	1521
Sum			130	364	18012
Mean			10.83	30.33	1501.00

Table 44. Accuracy of the Box-Jenkins Forecast for the F-111.

forecasted sortie values and the accuracy of the moving average and the modified moving average techniques.

For the Winters' Linear and Seasonal Exponential Smoothing technique, the seasonal smoothing constant, β, was .180, the trend smoothing constant, α, was .005, and the randomness smoothing constant, γ, was .007. The Durbin-Watson statistic was 2.8 and the Ljung-Box statistic was 24.58 with 16 degrees of freedom. The χ^2 table value for 16 degrees of freedom at the 95% confidence level was 26.30. Both statistics indicated that the models were adequate. The Winters' forecasted sortie values and the MSE are recorded in Table 43.

For the Box-Jenkins forecasting technique the Durbin-Watson statistic was 2.1 and the Ljung-Box statistic was 8.28 with 14 degrees of freedom.

The χ^2 table value for 14 degrees of freedom at the 95% confidence level was 23.68. Again, both statistics indicated that the models were adequate. The Box-Jenkins forecasted sortie values and the MSE are recorded in Table 44.

Analysis of the Forecasting Techniques for the F-111 Data

All four time series forecasting techniques yielded lower MSE values than the wing's MSE value of 5,731.75. The modified moving average technique had the lowest MSE value with 1,101.17. This was an 81% reduction in the MSE value. The months of June and August had the highest squared error values. The historical data for June indicated that the data values were within one standard deviation of the mean for all four fiscal years. However, the high squared error value was due to the fact that the number of sorties flown for the forecasted year was greater than the adjusted historical sortie data. On the other hand, the historical data for August indicated that the data value for fiscal year 1985 was greater than one standard deviation above the mean and the data value for fiscal year 1986 was almost two standard deviations below the mean. The lower forecasted data value was influenced by sudden downturn in 1986.

Month	Actual Sorties Flown	Forecast	Error	Absolute Error	Squared Error
Oct	1620	1899	-279	279	77841
Nov	1728	2127	-399	399	159201
Dec	1403	1672	-269	269	72361
Jan	1599	1873	-274	274	75076
Feb	1314	1827	-513	513	263169
Mar	1720	1998	-278	278	77284
Apr	1944	2088	-144	144	20736
May	1566	1840	-274	274	75076
Jun	1539	1623	-84	84	7056
Jul	1639	1745	-106	106	11236
Aug	1671	1922	-251	251	63001
Sep	896	1021	-125	125	15625
Sum			-2996	2996	917662
Mean			-249.67	249.67	76471.83

Table 45. Accuracy of the Wing Forecast for the F-15.

Month	Actual Sorties Flown	Forecast	Error	Absolute Error	Squared Error
Oct	1620	1555	65	65	4225
Nov	1728	1542	186	186	34596
Dec	1403	1544	-141	141	19881
Jan	1599	1562	37	37	1369
Feb	1314	1573	-259	259	67081
Mar	1720	1571	149	149	22201
Apr	1944	1514	430	430	184900
May	1566	1538	28	28	784
Jun	1539	1536	3	3	9
Jul	1639	1531	108	108	11664
Aug	1671	1518	153	153	23409
Sep	896	1515	-619	619	383161
Sum			140	2178	753280
Mean			11.67	181.50	62773.33

Table 46. Accuracy of the Moving Average Forecast for the F-15.

Month	Actual Sorties Flown	Forecast	Error	Absolute Error	Squared Error
Oct	1620	1623	-3	3	9
Nov	1728	1592	136	136	18496
Dec	1403	1535	-132	132	17424
Jan	1599	1485	114	114	12996
Feb	1314	1431	-117	117	13689
Mar	1720	1836	-116	116	13456
Apr	1944	1515	429	429	184041
May	1566	1620	-54	54	2916
Jun	1539	1629	-90	90	8100
Jul	1639	1578	61	61	3721
Aug	1671	1681	-10	10	100
Sep	896	1137	-241	241	58081
Sum			-23	1503	333029
Mean			-1.92	125.25	27752.42

Table 47. Accuracy of the Mod. Moving Average Forecast for the F-15.

Month	*Actual Sorties* Flown	*Forecast*	*Error*	Absolute Error	Squared Error
Oct	1620	1592	28	28	784
Nov	1728	1550	178	178	31684
Dec	1403	1485	-82	82	6724
Jan	1599	1463	136	136	18496
Feb	1314	1436	-122	122	14884
Mar	1720	1801	-81	81	6561
Apr	1944	1456	488	488	238144
May	1566	1579	-13	13	169
Jun	1539	1590	-51	51	2601
Jul	1639	1559	80	80	6400
Aug	1671	1633	38	38	1444
Sep	896	1177	-281	281	78961
Sum			318	1578	406852
Mean			26.50	131.50	33904.33

Table 48. Accuracy of the Winters Forecast for the F-15.

Month	Actual Sorties Flown	Forecast	Error	Absolute Error	Squared Error
Oct	1620	1660	-40	40	1600
Nov	1728	1558	170	170	28900
Dec	1403	1432	-29	29	841
Jan	1599	1481	118	118	13924
Feb	1314	1550	-236	236	55696
Mar	1720	1963	-243	243	59049
Apr	1944	1377	567	567	321489
May	1566	1576	-10	10	100
Jun	1539	1589	-50	50	2500
Jul	1639	1614	25	25	625
Aug	1671	1582	89	89	7921
Sep	896	1283	-387	387	149769
Sum			-26	1964	642414
Mean			-2.17	163.67	53534.50

Table 49. Accuracy of the Box-Jenkins Forecast for the F-15.

Findings of the Forecasting Techniques for the F-15 Data

The accuracy of the wing's forecasted monthly sortie schedule and the sortie values are recorded in Table 45. Tables 46 and 47 record the forecasted sortie values and the accuracy of the moving average and the modified moving average techniques.

For the Winters' Linear and Seasonal Exponential Smoothing technique, the seasonal smoothing constant, β, was .344, the trend smoothing constant, α, was .161, and the randomness smoothing constant, γ, was .070. The Durbin-Watson statistic was 2.3 and the Ljung-Box statistic was 18.90 with 15 degrees of freedom. The χ^2 table value for 15 degrees of freedom at the 95% confidence level was 25.00. Both statistics indicated that the models

were adequate. The Winters' forecasted sortie values and the MSE are recorded in Table 48.

For the Box-Jenkins forecasting technique the Durbin-Watson statistic was 2.0 and the Ljung-Box statistic was 14.19 with 17 degrees of freedom. The χ^2 table value for 17 degrees of freedom at the 95% confidence level was 27.59. Again, both statistics indicated that the models were adequate. The Box-Jenkins forecasted sortie values and the MSE are recorded in Table 49.

Analysis of the Forecasting Techniques for the F-15 Data

In fiscal year 1987, the wing participated in an exercise called Coronet Warrior. Coronet Warrior was "a Tactical Air Command sponsored exercise designed to test the computer model used to build a war reserve supply kit (WRSK)" (16:74). As a result, the wing flew higher than normal sortie rates for June and July. The high sortie rates in the two months caused lower than normal sortie rates in other months of the fiscal year. Therefore, fiscal years 1983, 1984 and 1985 were used in the three forecasting techniques to predict fiscal year 1986.

All four time series forecasting techniques yielded MSE values lower than the wing's MSE value of 76,471.83. The modified moving average technique had the lowest MSE value of 27,752.42. This was a 64% reduction in the MSE value. The highest absolute error value occurred in the months of April and September. The historical data for April indicated that for fiscal year 1985 the data value was greater than one standard deviation below the mean. This caused the time series forecasting techniques to lower the forecasted

data value for the forecasted year. Also, the sorties flown for the forecasted year were dramatically greater than the adjusted historical sortie data for the previous fiscal years. These two factors resulted in the high squared error values for the time series forecasting techniques. Conversely, in September the actual sorties flown for the forecasted year were much lower than the adjusted historical sortie data for the previous fiscal years. This resulted in a high squared error value for that month.

IV. Conclusions and Recommendations

This chapter reviews the current methodology used in the Tactical Air Command (TAC) for forecasting the aircraft monthly sortie schedule. The number of scheduled aircraft has an effect on each work center's capacity to support the mission throughout the maintenance complex. To increase the accuracy of the forecasted monthly sortie schedule, four time series forecasting techniques were tested on historical sortie data from five different wings in TAC. The accuracy of the time series techniques was then measured using the mean squared error (MSE). Table 50 provides a summary of the MSE values for each forecasting technique. Also, the table records the ratio of the forecasting techniques' MSE value compared to the wing's MSE value. The MSE values were obtained from Tables 25-49 in the preceding chapter. The time series techniques which produced the most accurate forecasts will then be discussed. Finally, a recommendation is provided for the best method to use in determining the monthly aircraft sortie rates in the TAC.

Conclusion

The conclusions of this research are based on the findings of the time series forecasting techniques. These findings were compared to the results of the methodology currently used by the Tactical Air Command (TAC) for forecasting the monthly sortie schedule. This methodology is explained in Chapter I as a part of the operational planning cycle and is outlined in

Tactical Air Command Regulation 66-5, *Combat Oriented Maintenance Organization* and Tactical Air Command Regulation 60-5, *Aircraft and Aircrew Training Devices Flying Scheduling and Maintenance Planning Effectiveness*.

The operations planning cycle consists of three basic steps. First, the wing determines the monthly aircraft sortie goal based on the aircraft utilization rate assigned to the wing from Headquarters TAC. Then the wing adjusts the monthly sortie goals for the number of operational and maintenance days and the seasonal conditions of each month. Finally, the wing calculates an aircraft attrition factor for each month. The monthly attrition factor is based on an historical analysis of nonchargeable aircraft deviations from past aircraft sortie schedules. The monthly aircraft attrition factor is then used to determine the forecasted monthly aircraft sortie schedule for the next fiscal year flying program.

The number of aircraft sorties scheduled for each month affects the capabilities of the work centers throughout the maintenance complex. Maintenance supervisors can calculate their work center capacity requirements based on past performance data. This is then compared to the forecasted monthly sortie schedule to determine if the work center can support the number of monthly sorties. If it is determined that supporting the monthly sorties is beyond the capabilities of the work center, then the maintenance supervisor must make adjustments to that work center.

Since the methodology used in the operational planning cycle affects the work center capabilities throughout the maintenance complex, it follows that the operational planning cycle must be as accurate as possible. The operational planning cycle is concerned with future events that can be

forecasted. There has been a rapid growth in forecasting techniques over the past two decades. These techniques can be used in the planning process to predict future events more accurately. Forecasting techniques are generally defined in two categories: qualitative and quantitative. Qualitative forecasting techniques are used when historical data does not exist or are non-representative of current activities. On the other hand, quantitative forecasting techniques are used when historical data does exist. Since each wing reports the actual number of aircraft monthly sorties flown each month to Headquarters TAC, quantitative forecasting techniques were used in this research.

Quantitative forecasting techniques are further divided into two general categories: causal and time series. Causal techniques are used to forecast cause-effect relationships. In this case the dependent variable to be forecasted is a function of one or more independent variables. This technique determines the form of the relationship and uses it to forecast the future value of the dependent variable. Whereas, time series techniques are concerned with identifying patterns in historical data which are measured in periods of years, months, weeks, or days. Four time series techniques were chosen for the research. They were the moving average, modified moving average, the Winters' Linear and Seasonal Exponential Smoothing and the Box-Jenkins forecasting techniques.

The time series forecasting techniques were used with historical aircraft sortie data obtained from Headquarters TAC for five tactical fighter wings to determine which technique yielded the best forecast. Each wing represented a different weapon system -- A-10, F-4, F-16, F-111 and F-15. For the A-10 and F-111 data, four years of historical data were used with the time series forecasting techniques to forecast the fifth year. For the F-4, F-16 and F-15

data, three years of historical data were used. The forecasts were compared to the actual sorties flown in the fifth year to determine which technique was the most accurate. The mean squared error (MSE) was used to measure the relative accuracy of the various forecasts. The MSE is the mean of the squared difference between the actual observed values from the forecasted values.

Before the historical sortie data was used in the time series techniques, adjustments were made to the data. This was done because the historical data indicated the number of aircraft and the utilization rate varied over each time period for each weapon system. The adjustment standardized the historical data to the forecasted year's number of aircraft and utilization rate. The historical data did not include the actual number of aircraft used for during each period. In order to determine the number of aircraft for each time period, the average number of total actual sorties flown was divided by the recorded utilization rate. This number was used for each month in the time period for the data adjustment. This procedure is considered a limitation in the research because it may not reflect the actual number of aircraft used during each month in the different time periods. If the actual number of aircraft used each month was available, then the time series forecasting techniques would have been more accurate.

A summary of the MSE values is shown on the next page in Table 50 for each forecasting technique. Eight-six percent of the time series techniques produced more accurate forecasts than the wing's forecast. This figure excludes the F-4 data which is considered to be non-representative of the current operations at the wing. In fact, the best performance was for the F-111 data where the modified moving average technique reduced the MSE value by 81%. The modified moving average technique produced the best

Forecasting Technique	A-10 Data		F-4 Data		F-16 Data		F-111 Data		F-15 Data	
	MSE	Ratio	MSE	Ratio	MSE	Ratio	MSE	Ratio	MSE	Ratio
Wing	23,133.75	1.00	29,003.58	1.00	51,179.17	1.00	5,731.75	1.00	76,471.83	1.00
Moving Ave	34,040.50	1.47	56,707.00	1.96	55,960.17	1.09	1,970.75	0.34	62,773.33	0.82
Mod Mov Ave	16,991.75	0.73	37,415.25	1.29	33,226.25	0.65	1,101.17	0.19	27,752.42	0.36
Winters	15,721.00	0.68	46,496.25	1.60	38,757.00	0.76	1,139.75	0.20	33,904.33	0.44
Box-Jenkins	14,091.75	0.61	34,958.42	1.21	34,136.08	0.67	1,501.00	0.26	53,534.50	0.70

Table 50. Summary of the Forecasting Techniques' Accuracy

forecast for 75% of the wings (once again excluding the F-4). The Box-Jenkins technique produced the best forecast for the remaining 25%.

Two factors indicate why the time series forecasting techniques did so well. First, the time series forecasts were based on the actual past sortie performance of the wing. This differs from the current forecasting methodology used in TAC which uses an attrition factor based on the lack of performance, nonchargeable deviations, of the wing. Second, adjusting the historical sortie data to the forecast year standardizes the data. At the beginning of each forecasted period, TAC assigns the wing an aircraft utilization (UTE) rate. The UTE rate may be higher or lower than preceding years. Also, the wing should have a fairly accurate indication of the number of aircraft it will possess for the forecasted period. Therefore, adjusting the historical sortie data to the number of aircraft and the UTE rate for the forecasted period aided the time series forecasting techniques in identifying the pattern in the historical data and projecting that pattern to the

forecasted time period. The current methodology in the operational planning cycle does not adjust the historical data to the forecasted time period.

Recommendation

As indicated in the conclusion, a more accurate forecast of the monthly sortie schedule can be achieved by using a time series forecasting technique, specifically the modified moving average technique which produced the best forecast 75% of the time. The increase in forecast accuracy will enable each wing to more effectively schedule its assigned aircraft and personnel.

To accomplish this, the modified moving average technique should be incorporated into the operational planning cycle to forecast the monthly sortie schedule. The forecast should be based on the wing's historical sortie performance. The historical sortie data should then be adjusted to standardize the data for the number of aircraft and the aircraft UTE rate for the projected year.

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BLOCK 19. Abstract

This research compared the results of four time series forecasting techniques to the forecasting methodology used at wings in the Tactical Air Command (TAC) for determining the monthly aircraft sortie schedule. The number of aircraft scheduled has an effect on the work force throughout the maintenance complex. A more accurate forecasted monthly sortie schedule results in the effective use of the wing's aircraft and personnel.

To accomplish the comparison, five years of historical aircraft sortie data for five different wings were obtained from Headquarters Tactical Air Command. Four of the years were used with the four time series techniques to forecast the fifth year. The forecasts were then compared to the actual data of the fifth year to determine which technique yielded the best results.

The results of the research indicated that 86% of the time series techniques out performed the current forecasting methodology used in TAC. The best performance of the time series techniques was the modified moving average which, for one wing, was 81% more accurate.